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NUMBER D2-90549

UNCLASSIFIED TITLE MAXIMUM ARM REACH ON INSTRUMENT RACKS

FROM THE SEATED POSITION

MODEL NO. CONTRACT NO.

ISSUE NO. ISSUED TO

AD060/046

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SEATTLE, WASHINGTON

THE BOEING COMPANY

AD 601046

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CLASSIFIED TITLE Unclassified
(STATE CLASSIFICATION)

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ABSTRACT

The boundaries of maximum possible arm reach for tasks on vertical instrument racks were determined on a stratified sample of twenty subjects, when seated in a standard office chair. The limiting effects of 3-1/2 inch thick service shelves, varying in depth from 10 through 25 inches and in height from 27.9 to 30.1 inches, were measured together with "optimum" seat height and leg clearance.

The 5th, 50th, and 95th percentile reach contours show that shelf depths greater than 10 inches decrease arm reach, the amount being dependent upon shelf height. Service shelf depth, when at the optimum of height of 28 inches, should not be much greater than 20 inches if 95 percent of the operators are to reach a vertical display beneath it.

BACKGROUND

In designing optimum equipment arrangements, displays, and tasks for electronic systems control centers, it is necessary to consider operator "arm-reach." Arm reach is determined, for a given population, by the specific task to be performed and the physical constraints of the task situation.

The tasks to be performed in a control center consist of monitoring a considerable expanse of instrument racks arrayed in a wall-like display. Typically, the operator is seated in a common office chair which may be moved about at will.

These instrument racks are frequently provided with service shelves for writing and support for miscellaneous instruments.

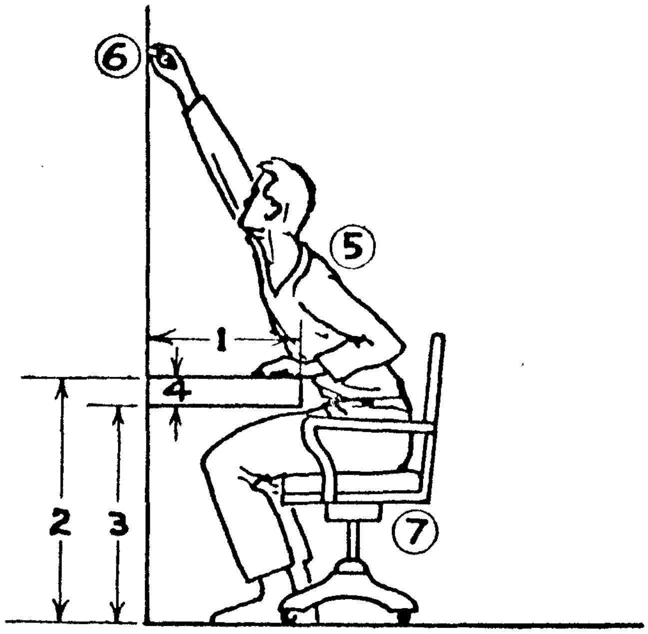
Since the task of monitoring such systems requires manipulating knobs, switches, buttons and plugs on the face of the vertical instrument rack arrays, it is important to know the maximum extent of the area of these racks within which the operator can reach and perform such manipulative tasks.

The literature of human factors research does not provide this information -- neither do military systems design specifications. Accordingly a study has been conducted to determine the size and shape of the maximum area on the face of a simulated vertical instrument rack within which seated operators can see and perform instrument rack-type manipulations. Also, the effects which the presence of service shelves has on this reach were determined.

Since, for a given body support, the height at which the operator chooses to sit is an important determiner of arm reach, a study was also done to determine both preferred seat height and the resulting leg clearances required beneath a service shelf.

SCOPE

The operator-instrument rack relationship studied is shown schematically in Figure 1. The important variables which affect arm reach are indicated.



Variables Affecting Reach:

1. Shelf depth
2. Shelf height
3. Shelf clearance
4. Shelf thickness
5. Operator size
6. Task
7. Body support

FIGURE 1. INSTRUMENT RACK/OPERATOR RELATIONSHIP STUDIED

Figures 2 and 3 show the actual apparatus used to examine reach, and Figure 4 is a scale drawing of this apparatus.

Variables one through four define the service shelf. They were treated in this study as follows:

1. Depth of Shelf -- Four shelf depths were studied: 0 (no shelf), 10 inches, 20 inches and 25 inches. The 10-inch shelf was 113 inches long and the 20 and 25-inch shelves were 80 inches long (see Figure 4). These lengths were necessary to prevent reaching around the ends of the shelves.

2. Shelf Height (Top Surface); and 3., Shelf Clearance -- The 10, 20 and 25-inch shelves were each tested at two heights above the floor: 27.9 inches and 30.1 inches. The current Air Force specification (1) of 30 inches as the minimum height for the top of the work surface of a console led to the

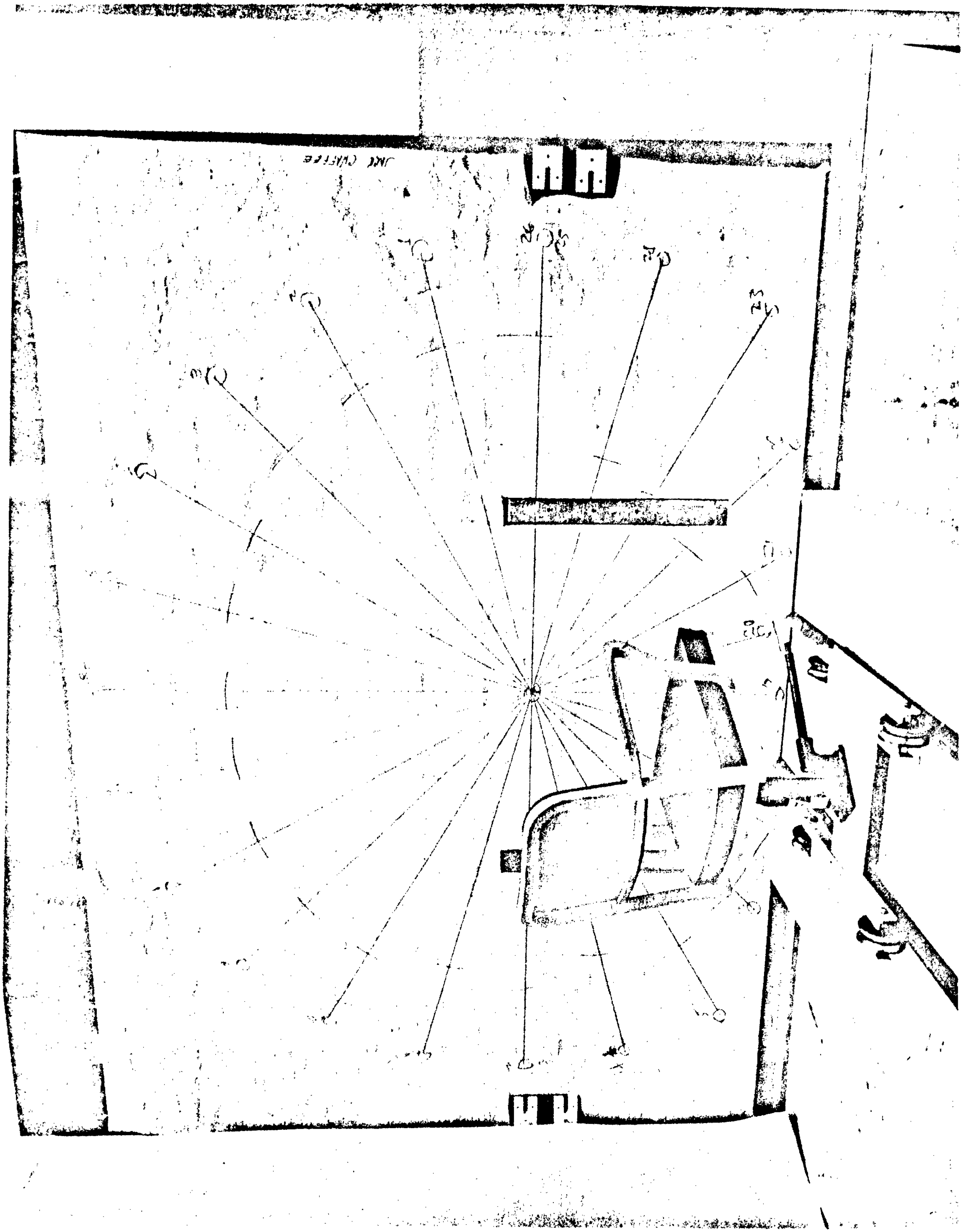


FIGURE 2 - REACH TASK MEASUREMENT APPARATUS: NO-SHELF CONFIGURATION.

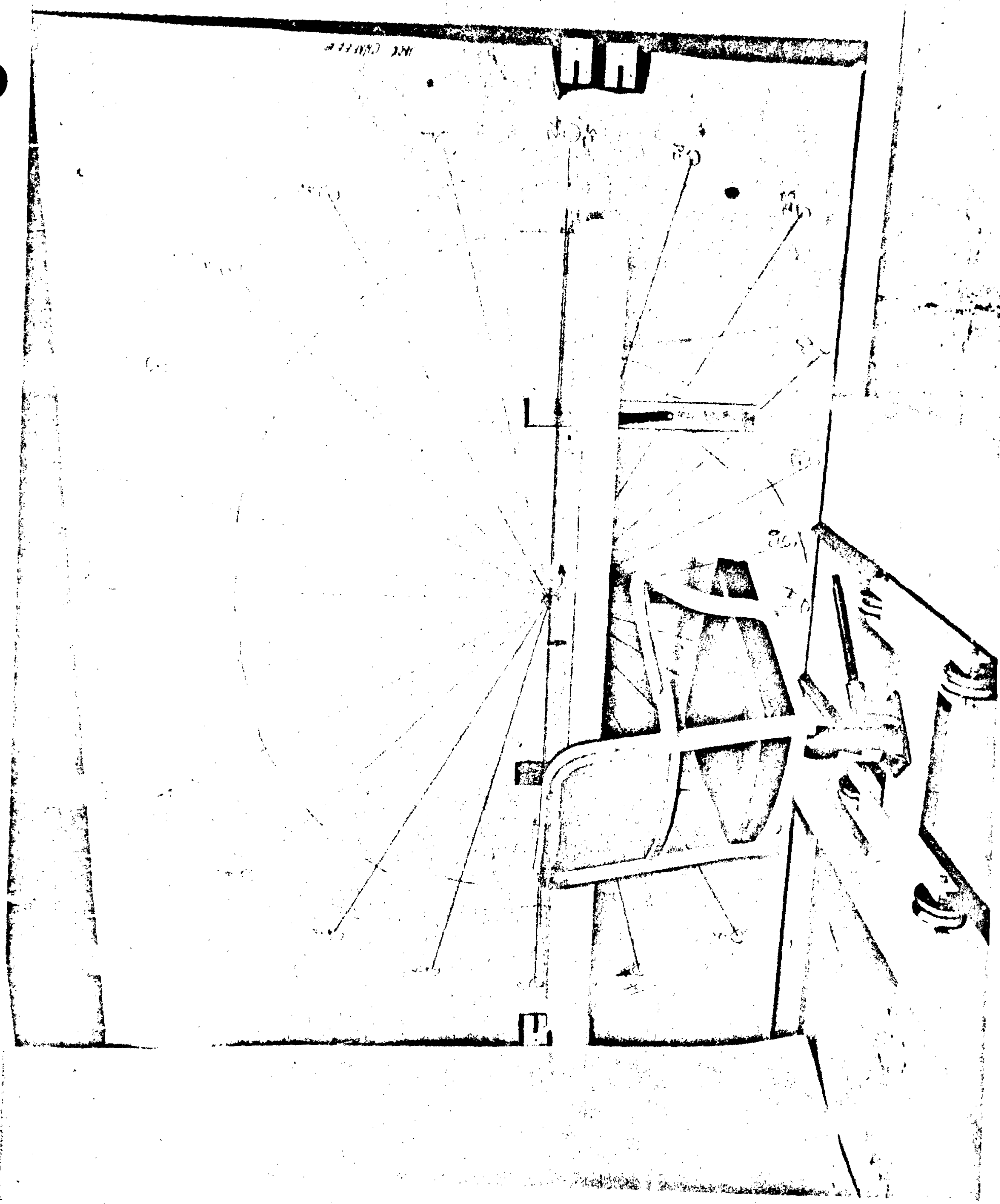


FIGURE 3 - REACH TASK-MEASUREMENT APPARATUS: 25-INCH SHELF CONFIGURATION.

REACH TASK MEASUREMENT APPARATUS

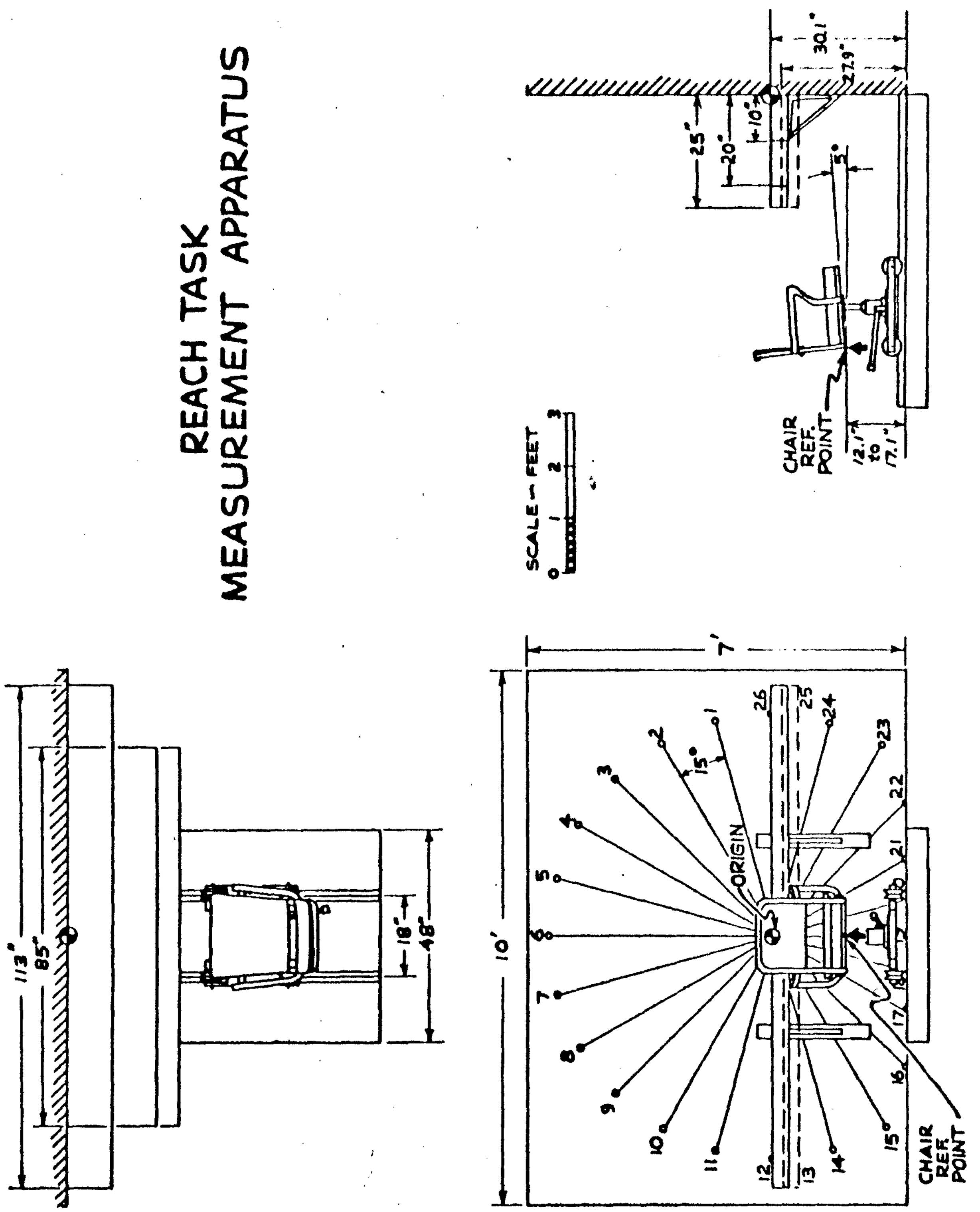


FIGURE 4

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selection of the 30.1-inch height, even though numerous studies (2) have shown that this is several inches above the most desirable height for a seated work surface. The 25-inch deep shelf is shown positioned at 30.1 inches in Figure 3 and Figures 9 through 13.

The lower shelf position of 27.9 inches was determined by first estimating minimum seated leg clearance beneath the shelf and then adding to this the shelf thickness to be used. Anthropometric data on the static seated posture (3) show that the 95th-percentile value of the distance from the sole of the bare foot, flat on the floor, to the top of the knee is 23.3 inches. Allowing 1.1 inches for shoes (4), the minimum clearance for accommodating 95 percent of the expected operators in the static posture was estimated to be 24.4 inches. With the 3.5-inch thick shelf used in this study, this dictated a minimum shelf-top height of 27.9 inches.

4. A shelf thickness of 3.5 inches was selected as the midpoint of the three-to-four-inch range commonly used both for service shelves as well as for office desk tops having center drawers.

The remaining variables affecting arm reach were treated thusly:

5. Operator Size -- Twenty male subjects were selected for this study according to a stratified sampling procedure based upon the known distribution of stature in the military population (3). This insured that the effects of body size upon observed arm reach would be similar to the effects expected in the using or "model population" consisting of a mixture of civilian and military instrument-rack operators.

It was assumed that there would be no difference in body size between the military population and the model population. Stature was used as the sole criterion of selection because it is the best single estimator (5) of those body dimensions believed to primarily influence arm reach in this situation.

6. The task consisted of grasping a special knurled knob (shown in Figure 5) in the right hand and pressing its base against a simulated instrument rack as near as possible to numbered targets. These targets were arranged at 15-degree intervals in a circle about a center or origin. The origin is identified on Figures 2 through 4 by the symbol ⊕, and was located on the simulated rack 30.1 inches above the floor.

The reach targets were placed far enough out from the origin to preclude, except in a few instances, being touched by the subjects. This was done to insure a truly maximum effort in reaching.

Figure 5 shows the knurled knob, which was fitted with a spring-loaded pencil lead to leave a mark at maximum reach. The broad flange at the knob's base was pressed against the simulated rack during reach. This required 28 ounces of pressure. In gripping the knob, the only constraint imposed was that the thumb and at least one finger touch this flange.

Figures 6 through 8 show the type of knob grips observed in the study.

The order of reaching toward the target was controlled by the observers and was indicated to the subject by verbal instructions and the use of a pointer as seen in Figures 9 through 12.

The right hand was used throughout this study for simplicity and because there is no significant difference between right and left-hand reach.

The subjects were encouraged to attempt to reach each target several times since their reach to given target seemed to improve with experience. Of the several resulting marks indicating maximum reach toward a given target,

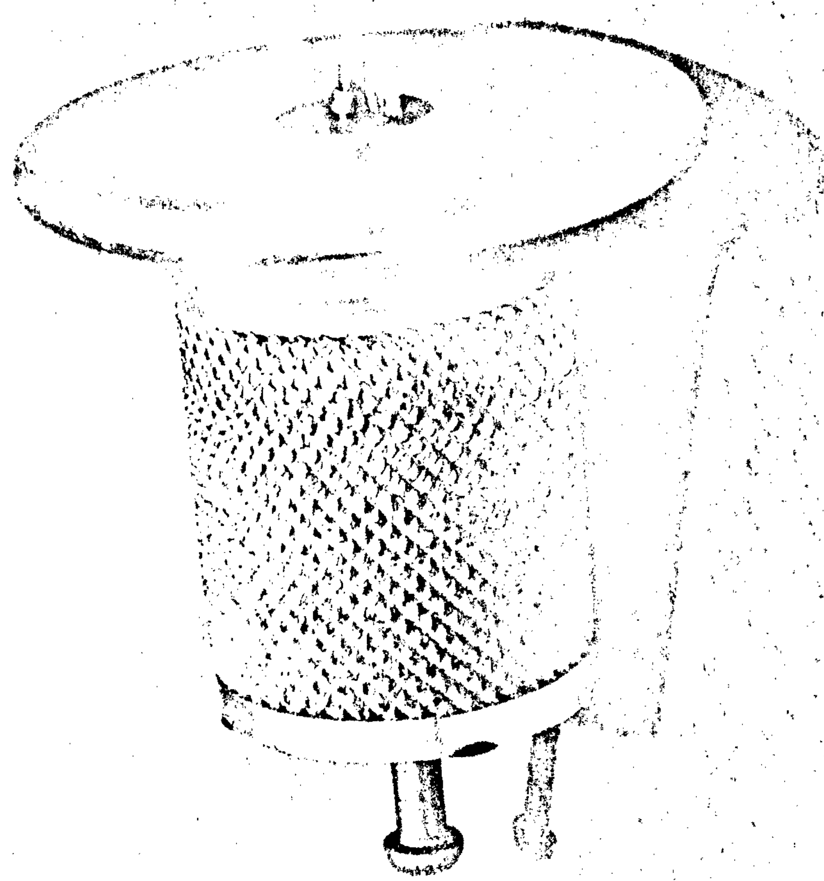


FIGURE 5 - SIMULATED KNOB WITH SPRING-LOADED PENCIL LEAD.

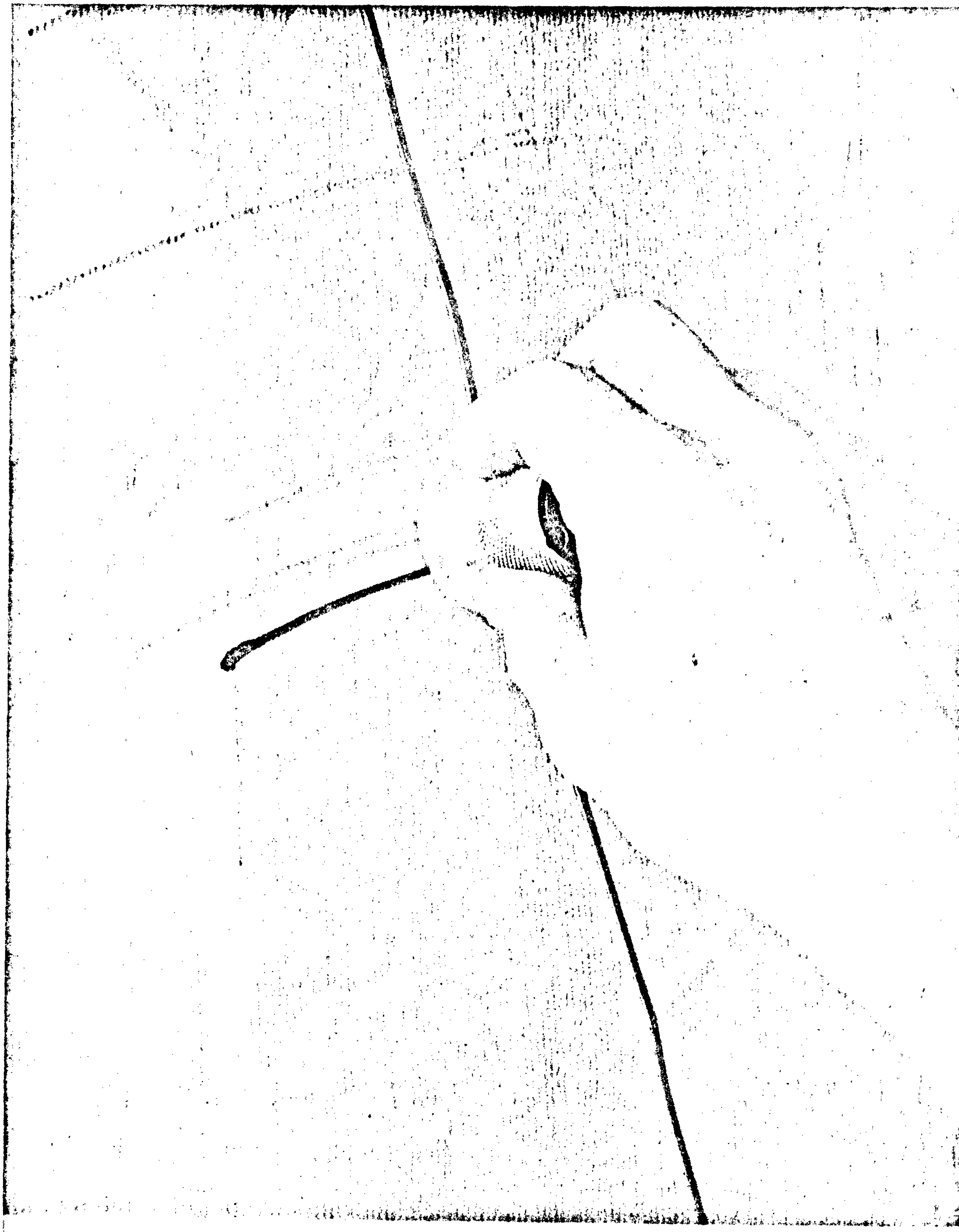


FIGURE 6 - KNOB GRIP TYPE A.

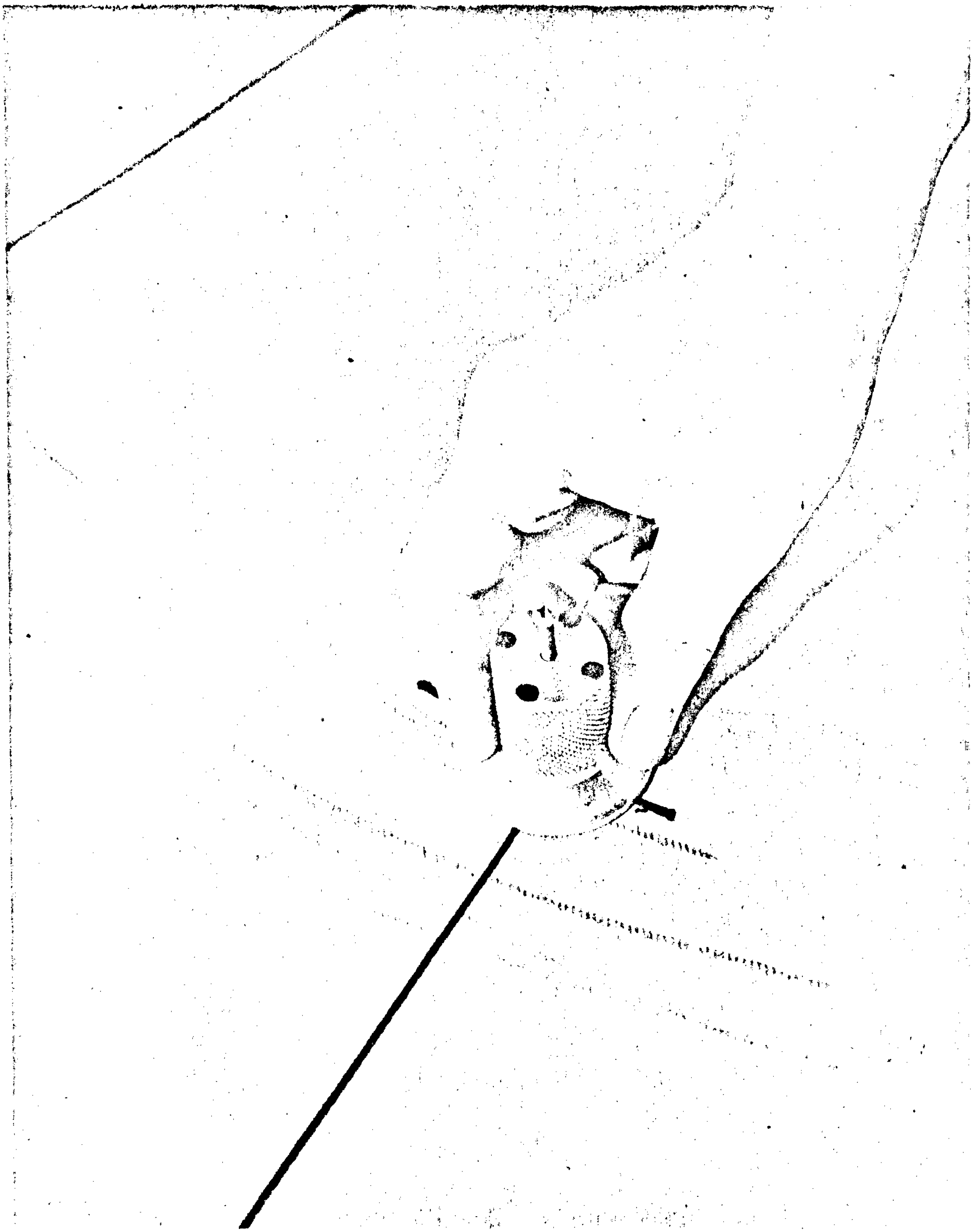


FIGURE 7 - KNOB GRIP TYPE B.

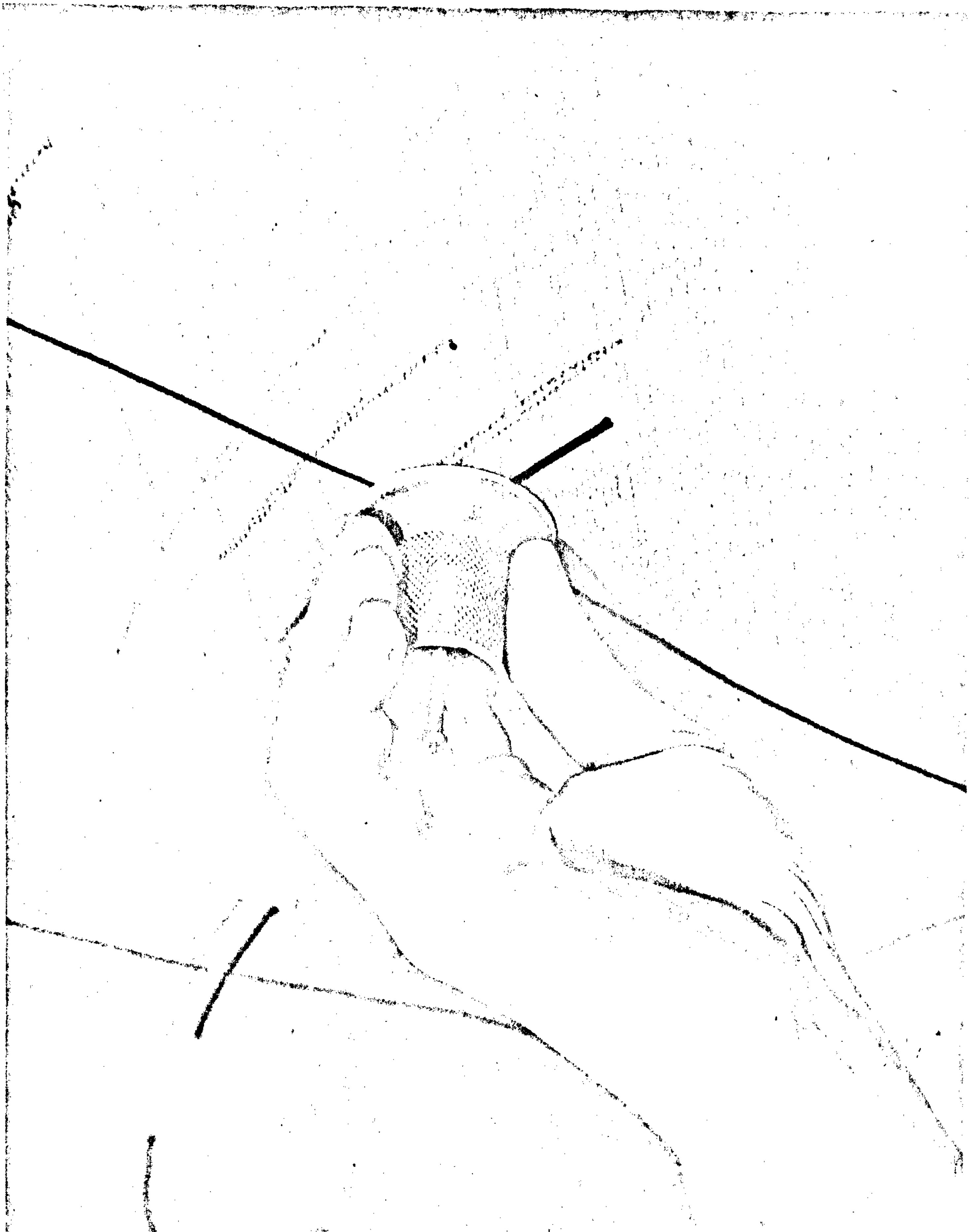


FIGURE 8 - KNOB GRIP TYPE C.

FIGURE 9 - REACH POSTURE TYPICAL OF AREA ABOVE SHELF AND TO RIGHT OF ORIGIN.

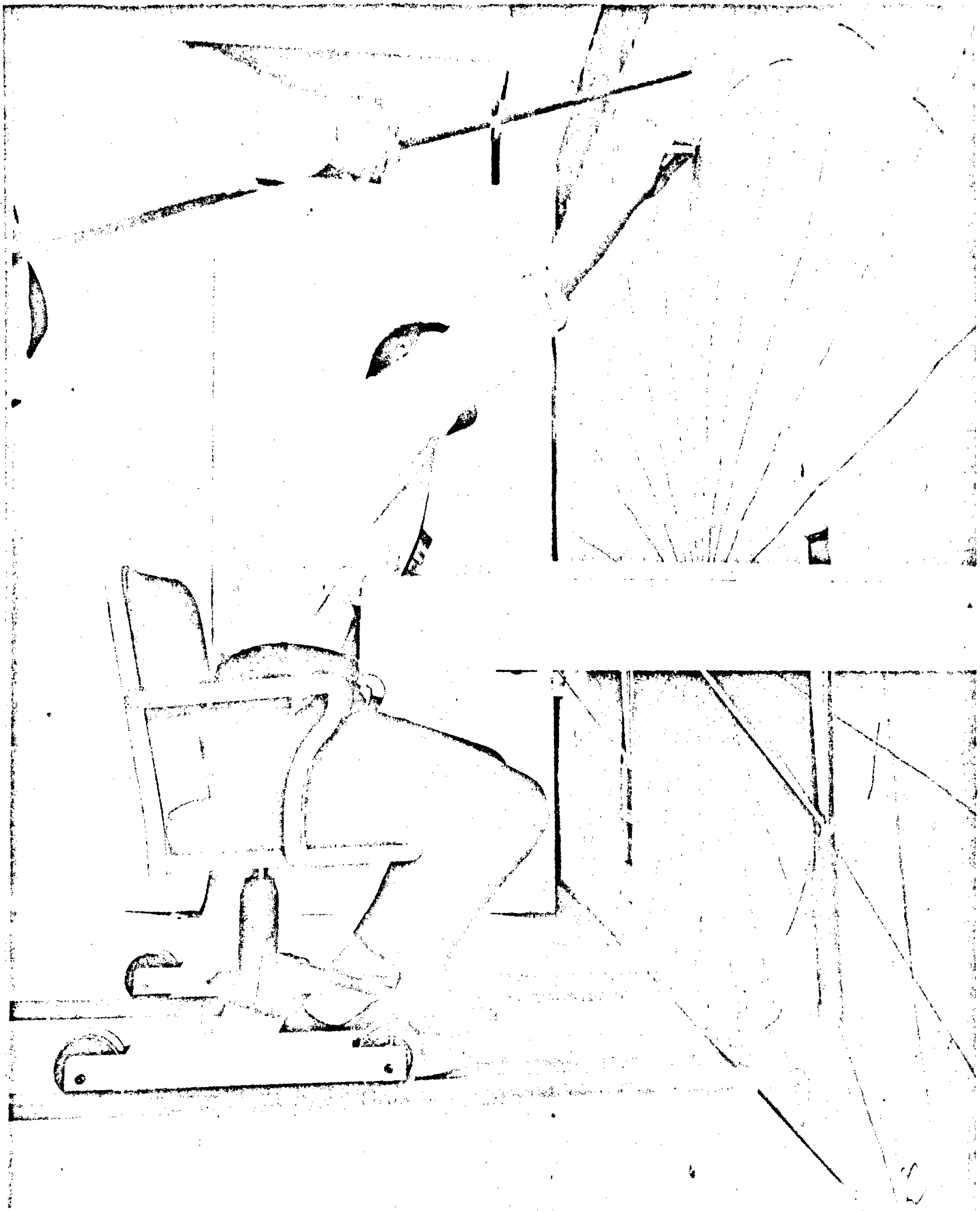


FIGURE 10 - REACH POSTURE TYPICAL OF AREA ABOVE SHELF DIRECTLY OVER ORIGIN.

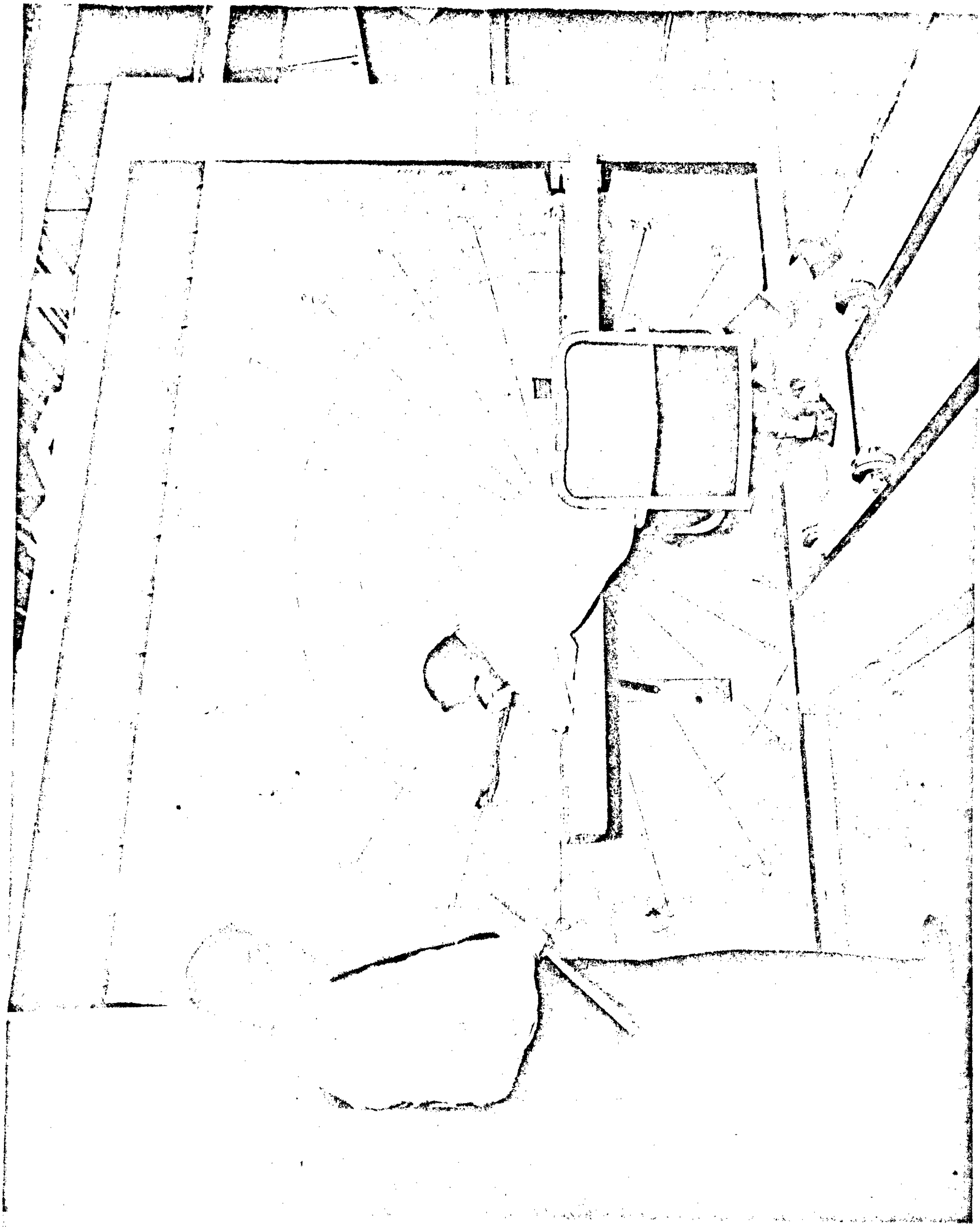


FIGURE 11 - REACH POSTURE TYPICAL OF AREA ABOVE SHELF TO LEFT OF ORIGIN.

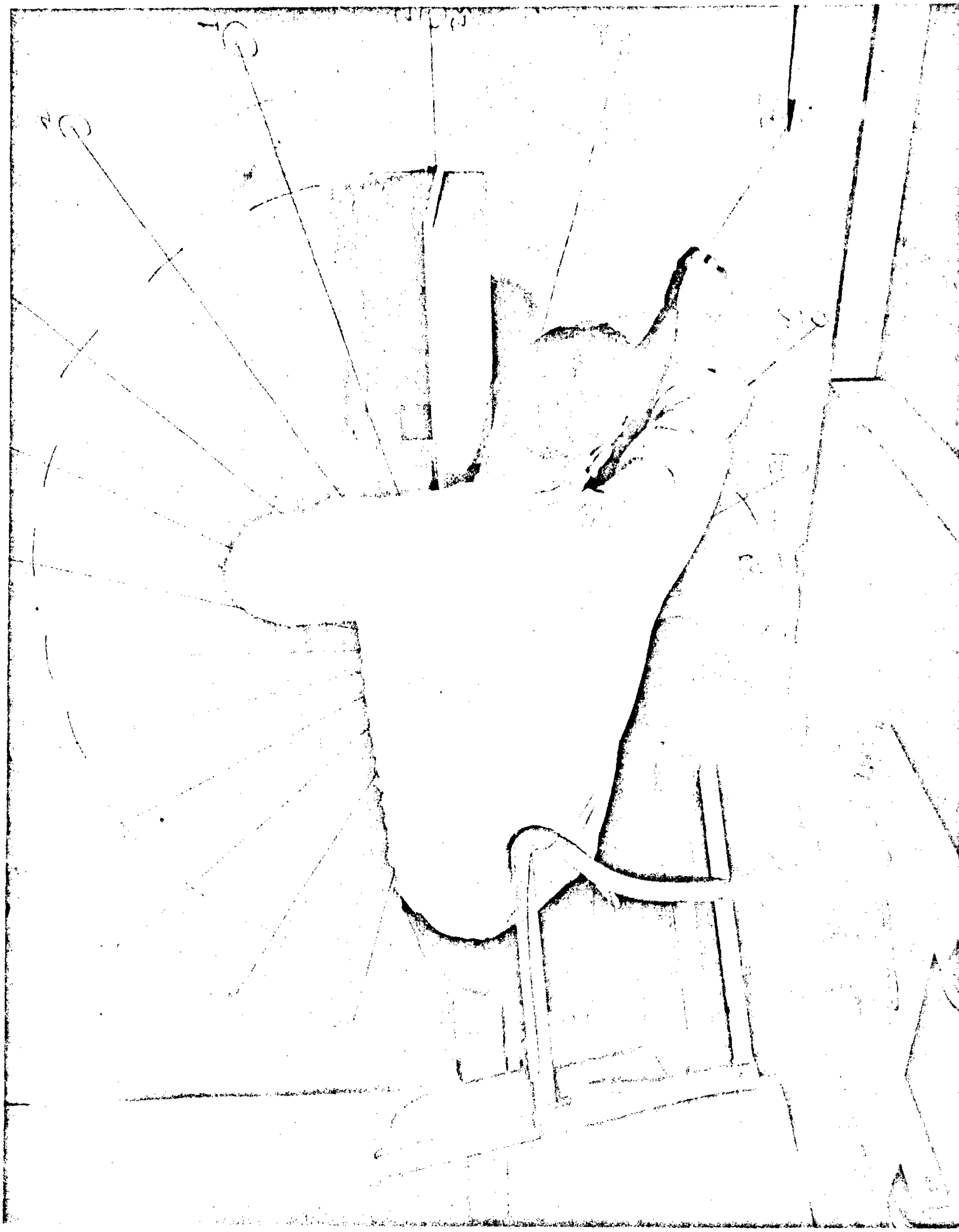


FIGURE 12 - REACH POSTURE TYPICAL OF AREA BELOW SHELF TO LEFT OF ORIGIN.

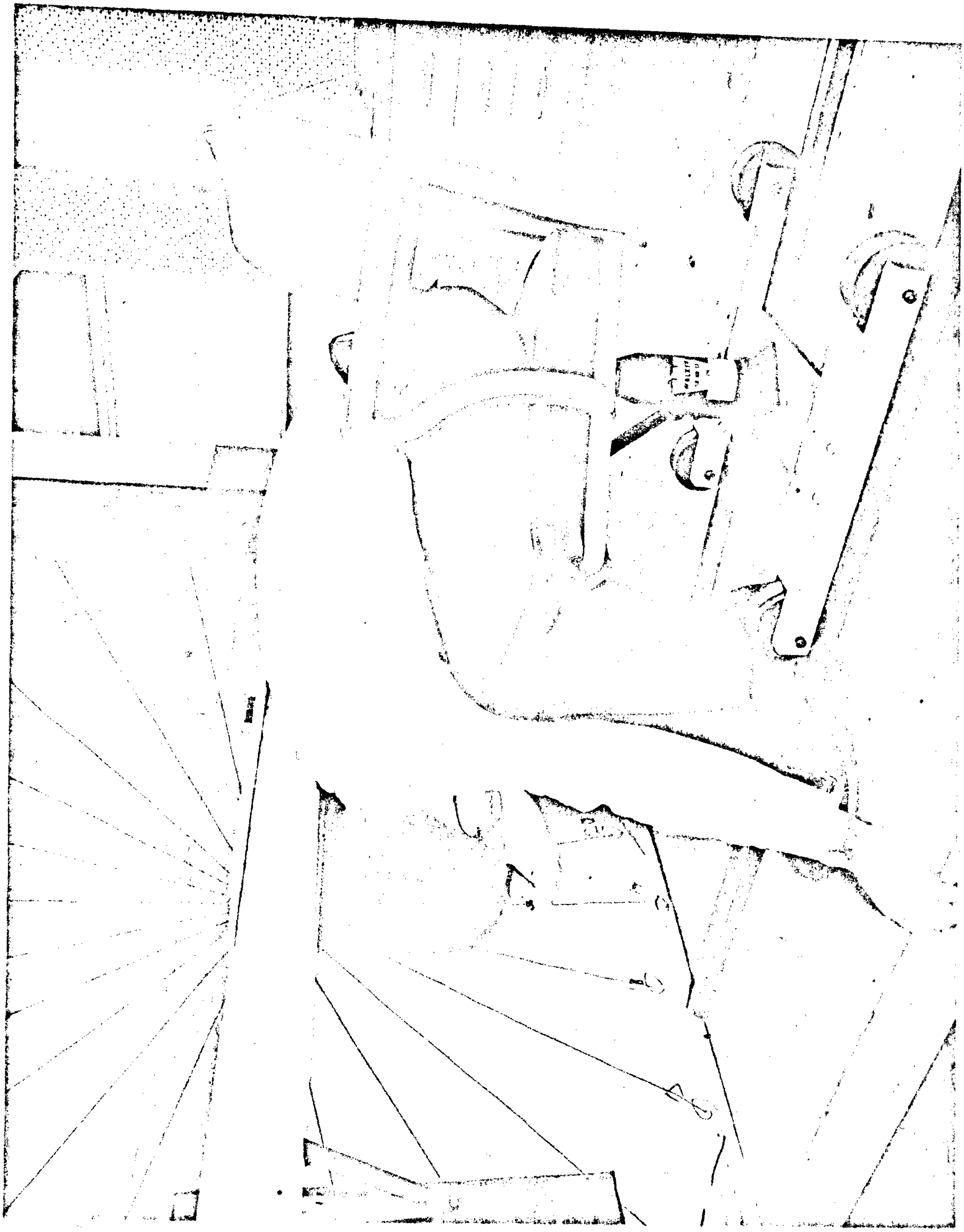


FIGURE 13 - REACH POSTURE TYPICAL OF AREA BELOW SHELF TO LEFT OF ORIGIN.

that which was farthest away from the origin was the one recorded.

It was required that the subjects be able to see the knob at all times.

Other than limiting performance to the right hand, only two artificial constraints were placed on the subjects' behavior in reaching the targets. These prohibitions were against:

a. Scooting forward in the chair from an initial position with the buttocks well back in the seat

b. Rising out of the chair, either by pulling up on the shelves or standing on the floor.

Figures 9 through 13 illustrate the relative freedom from constraint in "technique" enjoyed by the subjects as well as the body postures observed in reaching to the various quadrants of the simulated instrument rack. The four shelf depths and two shelf heights were presented in a different order for each subject in order to avoid consistent effects upon performance due to learning, order interaction, or other extraneous factors. This balancing plan is shown in the schematic below:

	Order of Conditions			
Subjects 1-5	0"	10" (U,D)	20" (D,U)	25" (U,D)
Subjects 6-10	10" (U,D)	25" (D,U)	0"	20" (U,D)
Subjects 11-15	20" (U,D)	0"	25" (D,U)	10" (D,U)
Subjects 16-20	25" (U,D)	20" (D,U)	10" (D,U)	0"

The letters D and U refer, respectively, to the 27.9 and 30.1-inch shelf heights.

7. <u>Body Support</u> -- Reach was performed by each subject seated at his "mean preferred seat height." The seat consisted of a swiveling/tilting office chair (Steelcase, Inc., 1120 East 36th St., Grand Rapids, Michigan). To facilitate vertical adjustment and limit lateral translational movement, the chair was modified as shown in Figure 14. The basic chair was mounted on a swivel atop a hydraulic jack (Series R, Walter Mfg. Co., Racine, Wisconsin) which in turn rested on a trolley. The trolley rolled on rails fastened to the floor at right angles to the simulated instrument rack, as shown in Figure 4.

Limitation of translational movement to a plane perpendicular to the simulated rack provided a fixed origin about which to plot arm reach.

Tilting was eliminated for simplicity of design. It was found to have no effect upon arm reach.

Seat height was defined as the height of chair reference point above the floor. Chair reference point (CRP) was defined as the marked (with tape) midpoint of the bottom rear edge of the lowest cross brace on the back of the chair and is shown in Figures 4 and 14. "Mean preferred seat height" was determined for each subject prior to reach measurement in the following manner:

a. The subject sat in the chair as shown in Figure 14 with buttocks as far back as was comfortable for a relaxed but alert attitude.

b. The seat height was then adjusted to each extreme, 17.9 inches above the floor to 12.1 inches above the floor, to acquaint the subject with sensations associated with the extremes.

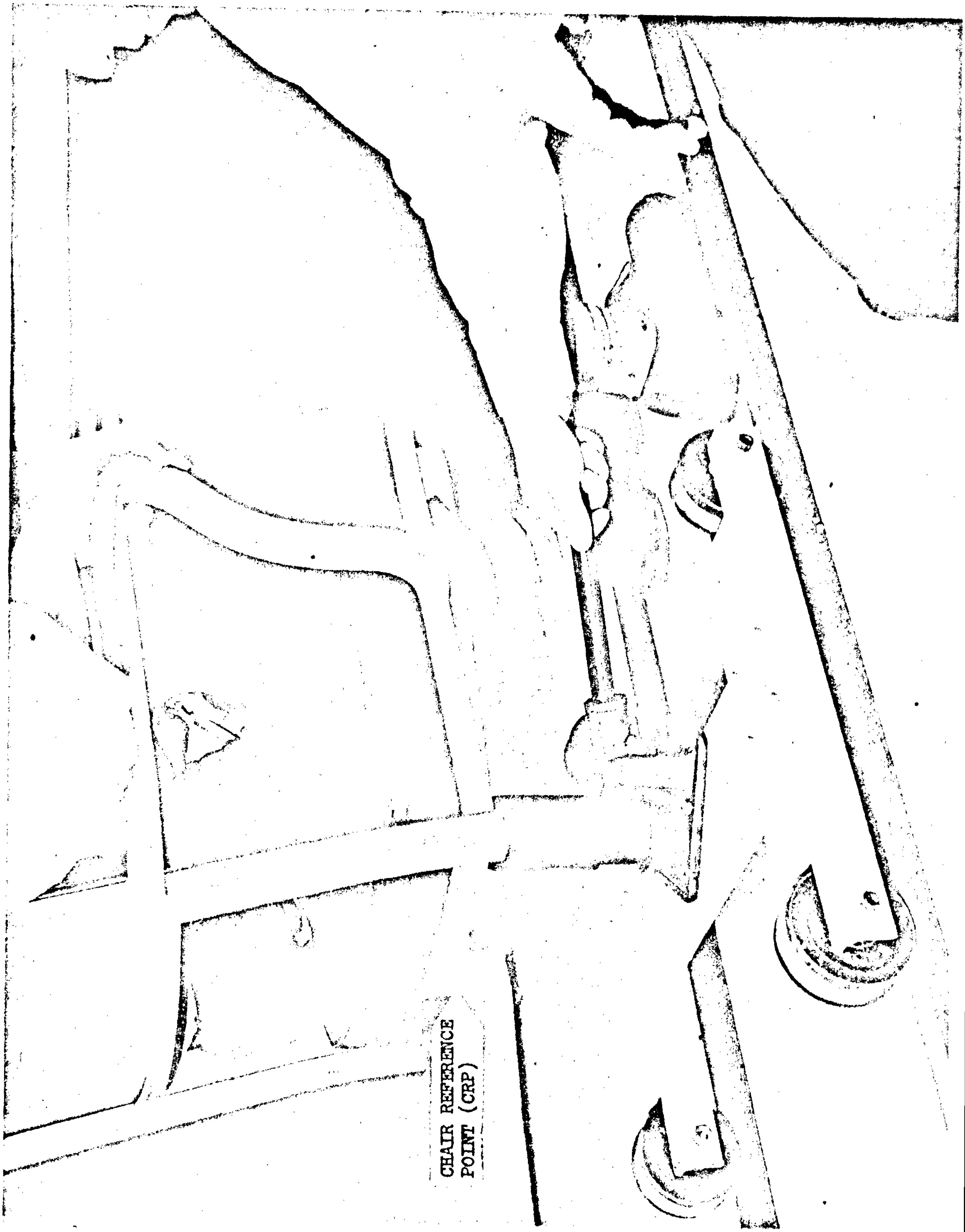


FIGURE 14 - STEELCASE OFFICE CHAIR ON HYDRAULIC JACK & TROLLEY. NOTE CHAIR REFERENCE POINT. (CRP).

c. The seat height was varied using the hydraulic jack and the subject was asked to report when a height was reached which he felt would be "comfortable" for prolonged sitting and yet which would allow convenient movement of the chair-trolley combination along the tracks.

d. Five trials were then made to identify preferred height. In each trial, the seat height was adjusted, starting from one or the other extreme and continuing in one direction without reversal, until the preferred height was reached.

Ten subjects started from the high extreme and were successively lowered, raised, etc., for five trials and ten started from the low extreme and were raised, lowered, raised, etc., in that order. This procedure tends to balance learning effects.

e. The results of the five trials of preferred seat height were averaged to define the "mean preferred seat height" used by that subject in performing the rack tasks.

The "minimum functional clearance" beneath a work surface such as a service shelf was defined as the clearance necessary to provide just adequate clearance for leg flexing and chair movement for the operator when seated with the chair reference point (CRP) adjusted to mean preferred height. Figure 15 illustrates the method of determining "minimum functional clearance" using a thin, 17-1/2-inch x 18-inch plate, which could be varied in height above the floor.

With the seat adjusted to his mean preferred seat height and the ankles flexed (toes up), the subject moved the chair back and forth on the rails. The plate was gradually lowered until contact with the undersurface was just

FIGURE 15 - BODY POSTURE & MEASUREMENT DEVICE FOR DETERMINING "MINIMUM FUNCTIONAL CLEARANCE."

noticeable to the subject. This plate height was defined as "minimum functional clearance" for the subject.

Preliminary tests showed that flexing the ankles was a convenient as well as easily reproduced way of insuring that resulting "functional clearance" would be sufficient to allow minimum leg movement for moving the chair about as well as for "squirming" during prolonged sitting.

RESULTS

A. Right-Handed Arm Reach

The quantitative results of the effects of shelf depth and shelf height on maximum arm reach for the task of simulated knob turning are summarized in the following numbered sheets, each of which collects the results of a unique combination of shelf depth with shelf height:

Shelf Depth	Shelf Height Above Floor 27.9"	Shelf Height Above Floor 30.1"
0"	Sheet 1	
10"	Sheet 2a	Sheet 2b
20"	Sheet 3a	Sheet 3b
25"	Sheet 4a	Sheet 4b

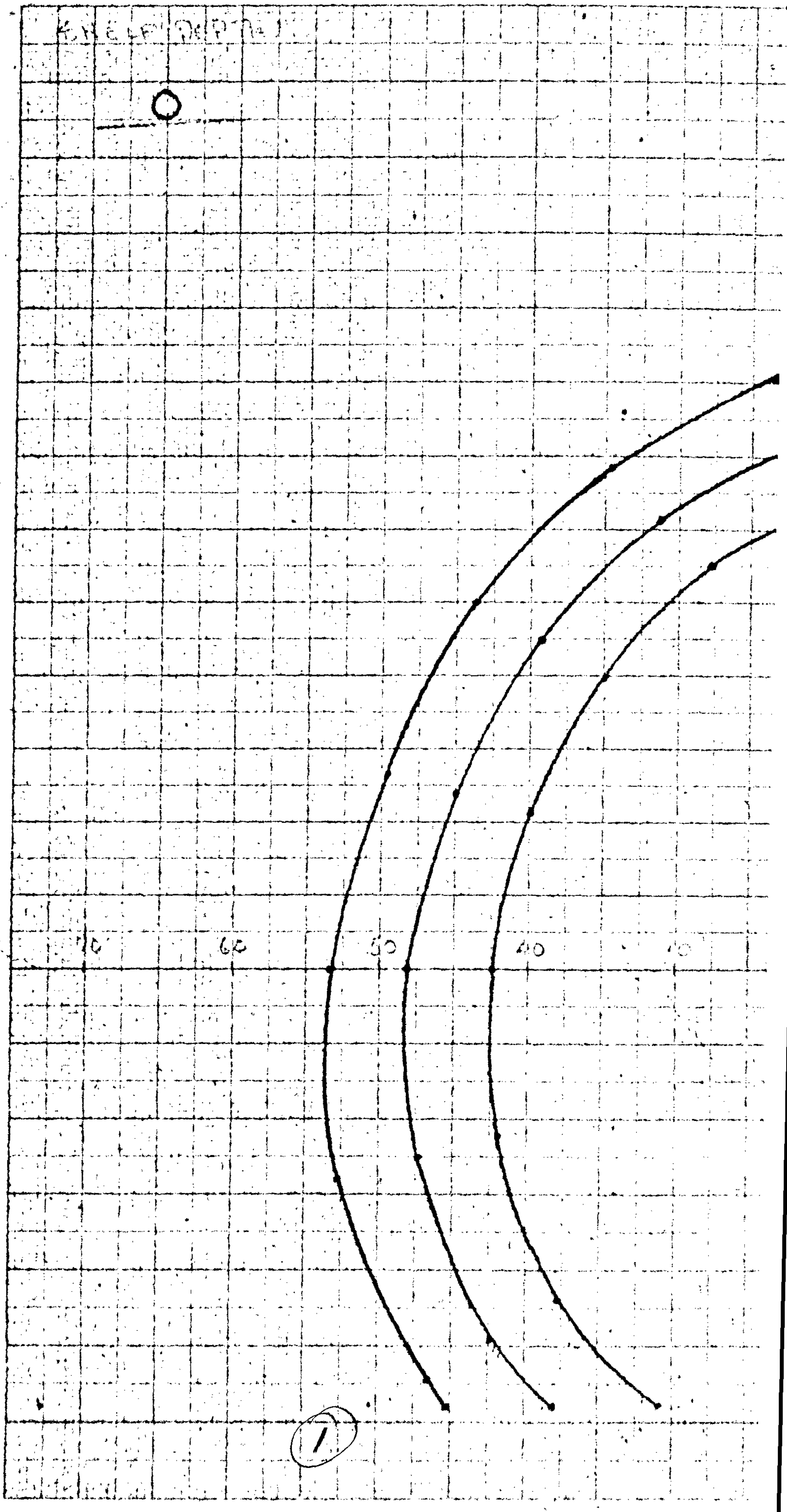
On each sheet, three contours or boundaries of arm reach are shown. The middle one, labeled "50th", is the statistical average or mean contour which is interpreted as the limits at or beyond which only 50 percent of the operators can perform the task. A task such as the one tested and located inside (i.e. toward the origin) this boundary can be performed by at least 50 percent of the operators.

The outer contour, labeled "95th", is the 95th-percentile boundary. Only 5 percent of the operators can perform the task at or beyond this contour. Conversely, it is expected that about 95 percent of the operators can perform the task only if it is located inside this boundary.

The inner contour, labeled "5th", is the 5th-percentile boundary. At least 95 percent of the operators can perform the task if it is located on or within this boundary. About 5 percent of the expected operators cannot even reach to this contour.

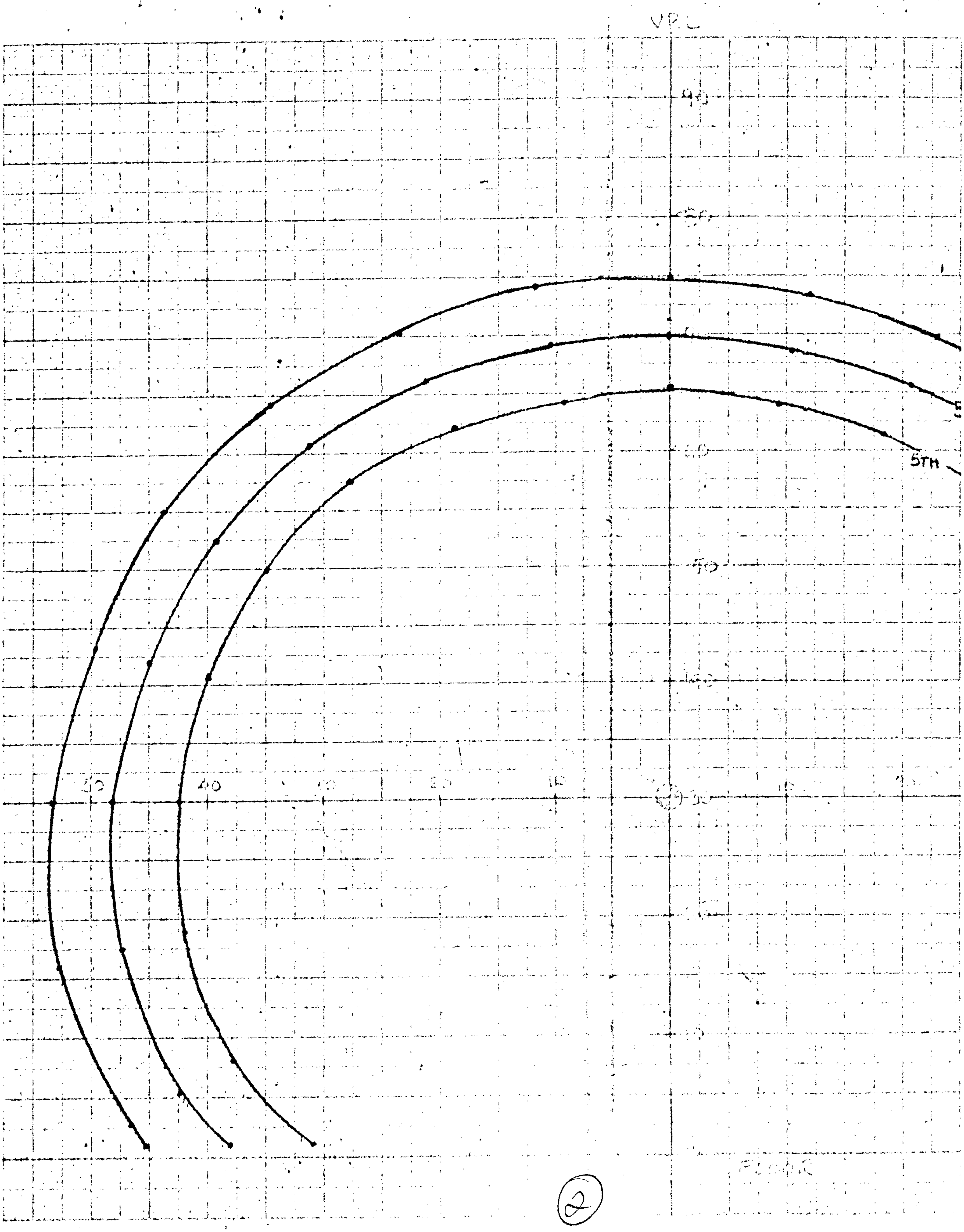
INSTRUMENT

SHEET 1

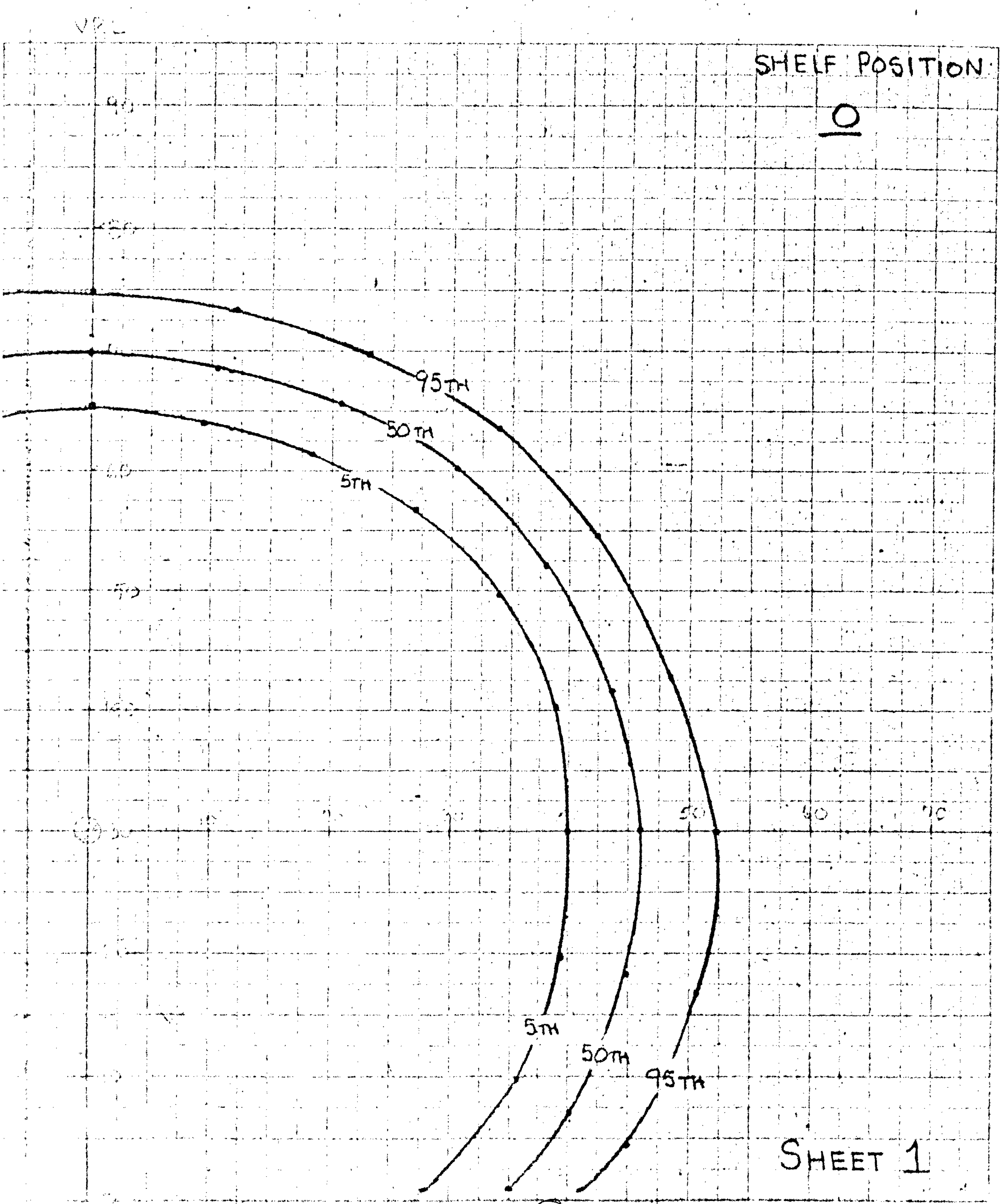


ENGRAVING 334-3 10 X 10 TO THE HALF INCH

INSTRUMENT RACK ARM REACH



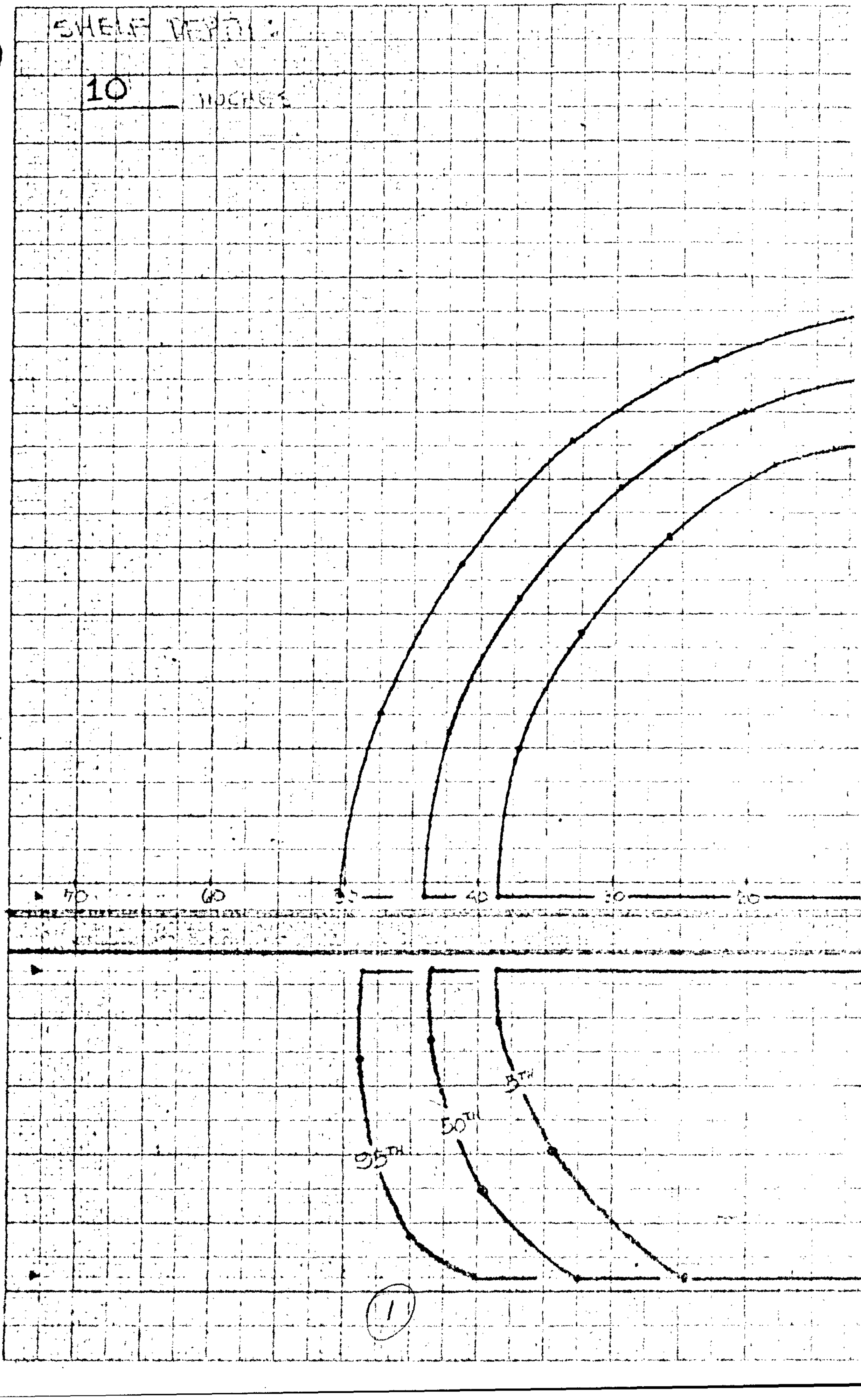
ARM REACH - RIGHT HAND



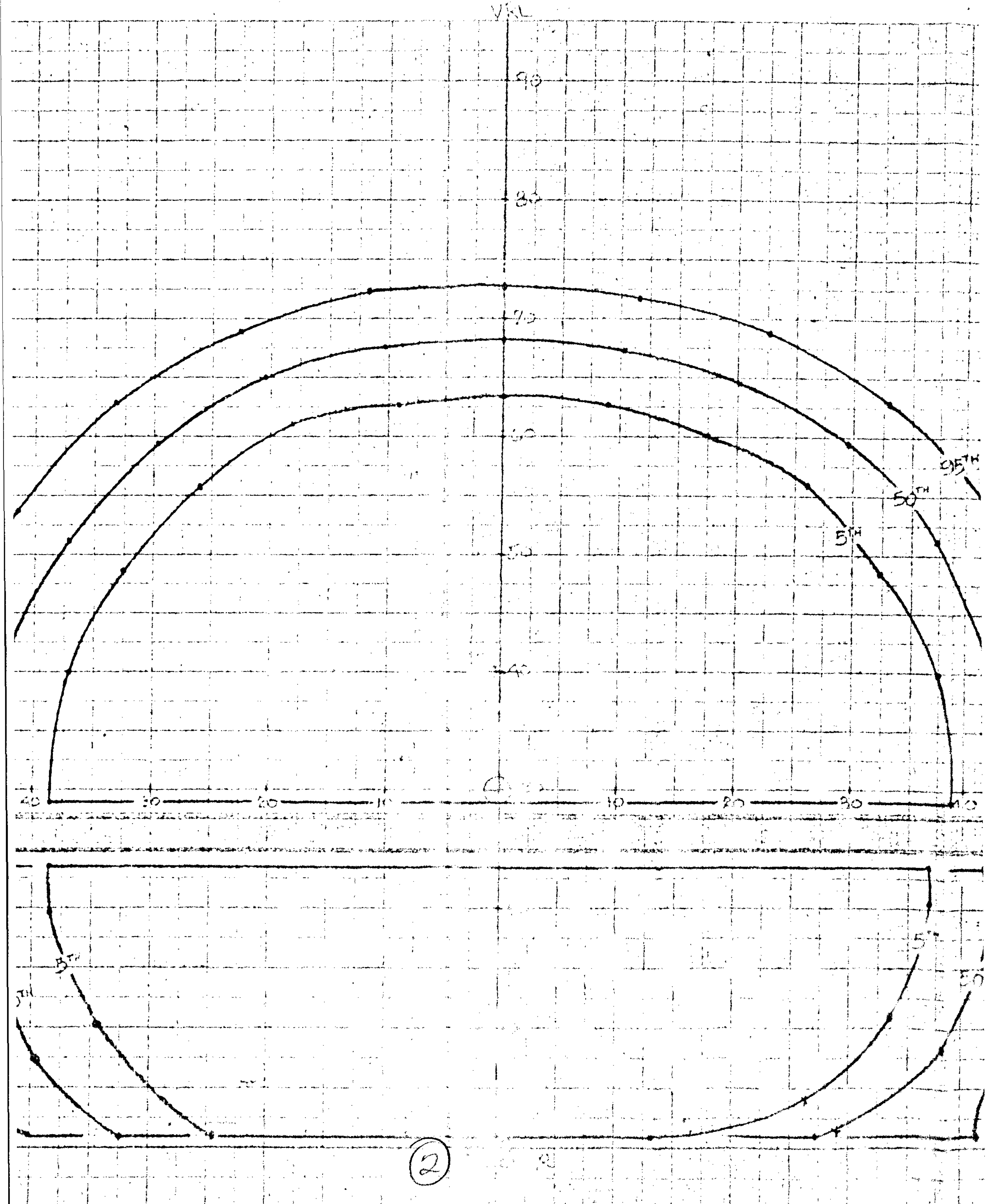
(3)

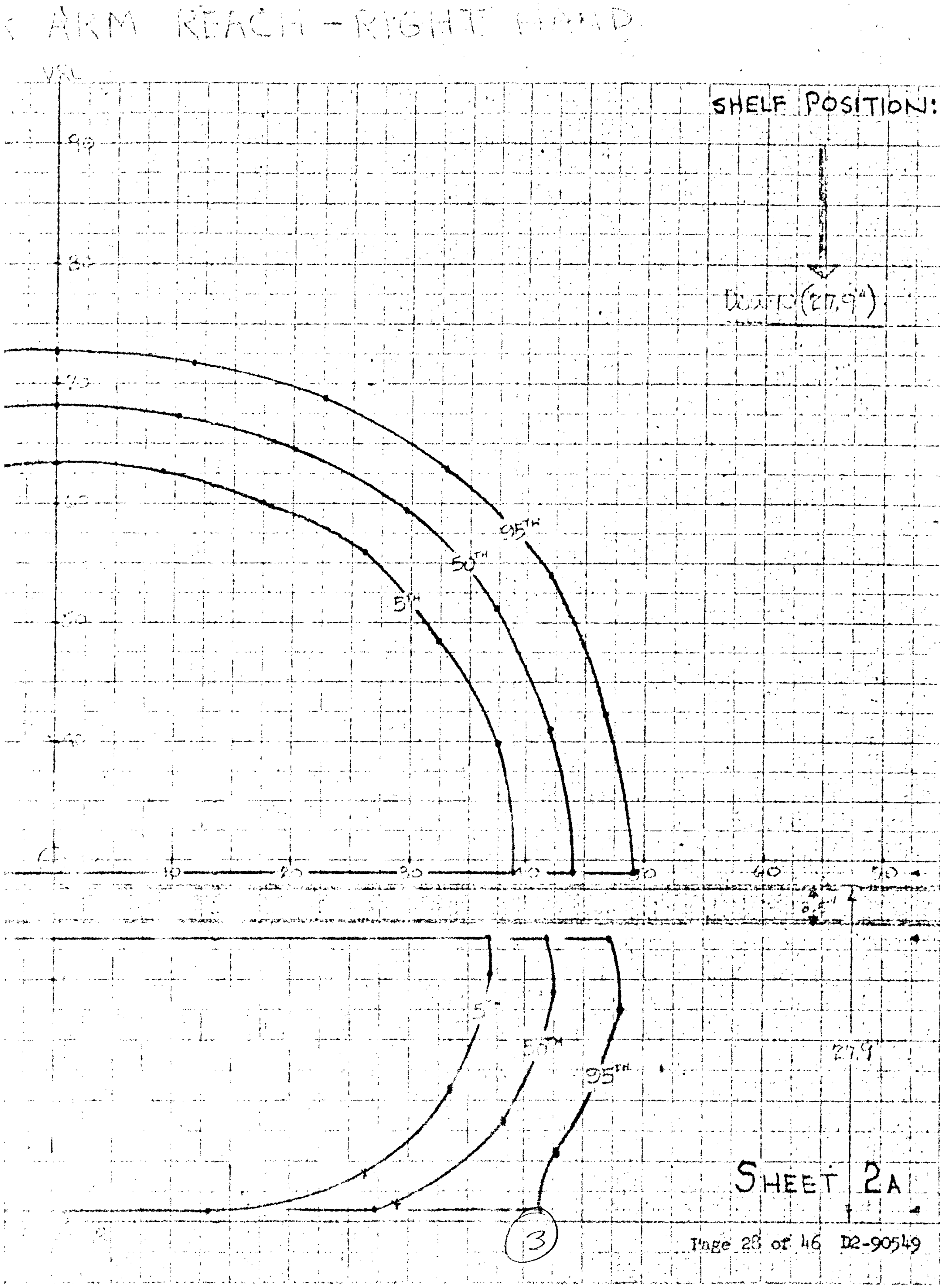
INSTRUMENT

SHEET 2A



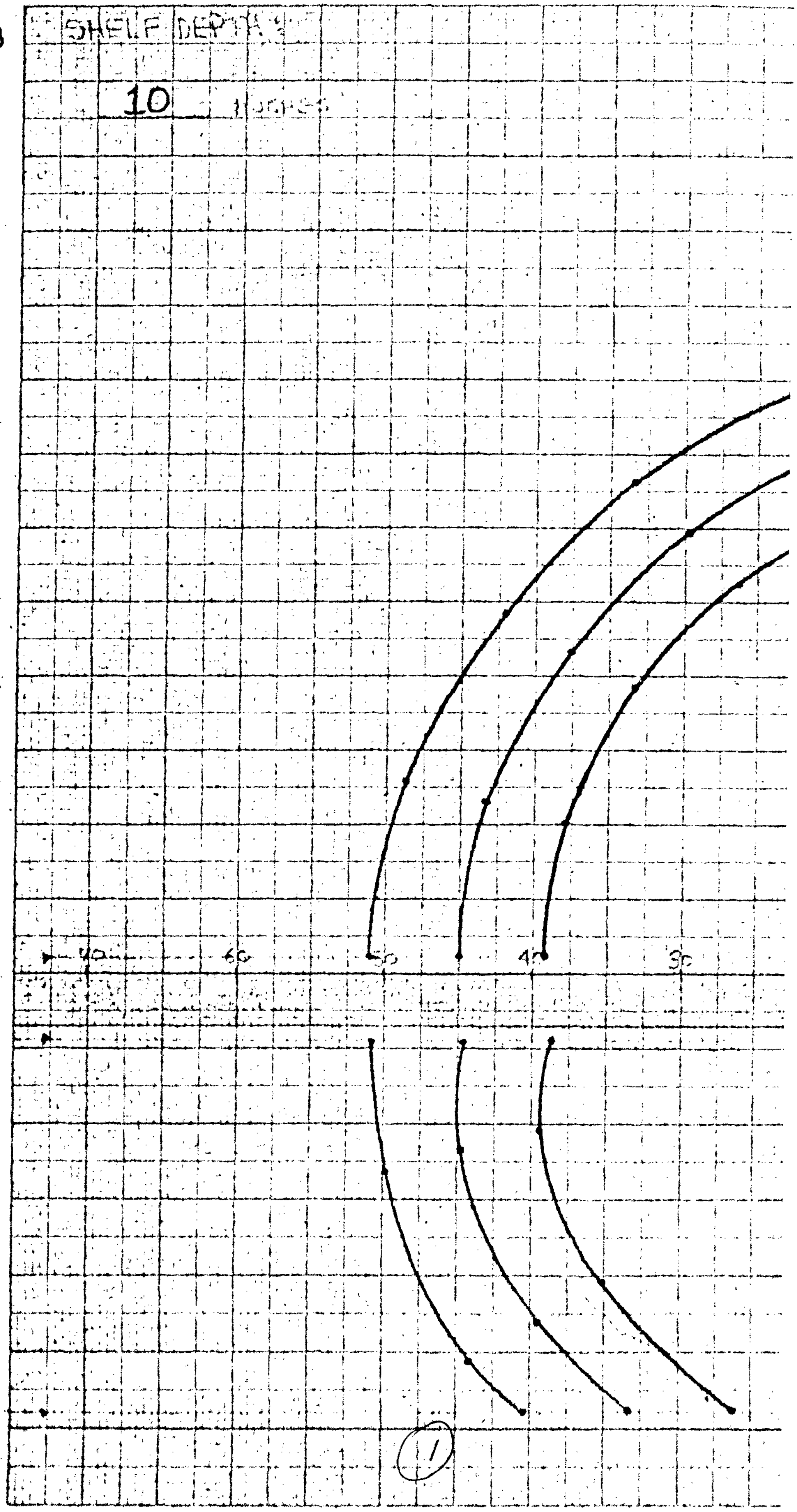
INSTRUMENT RA.. ARM REACH - RIGHT ..



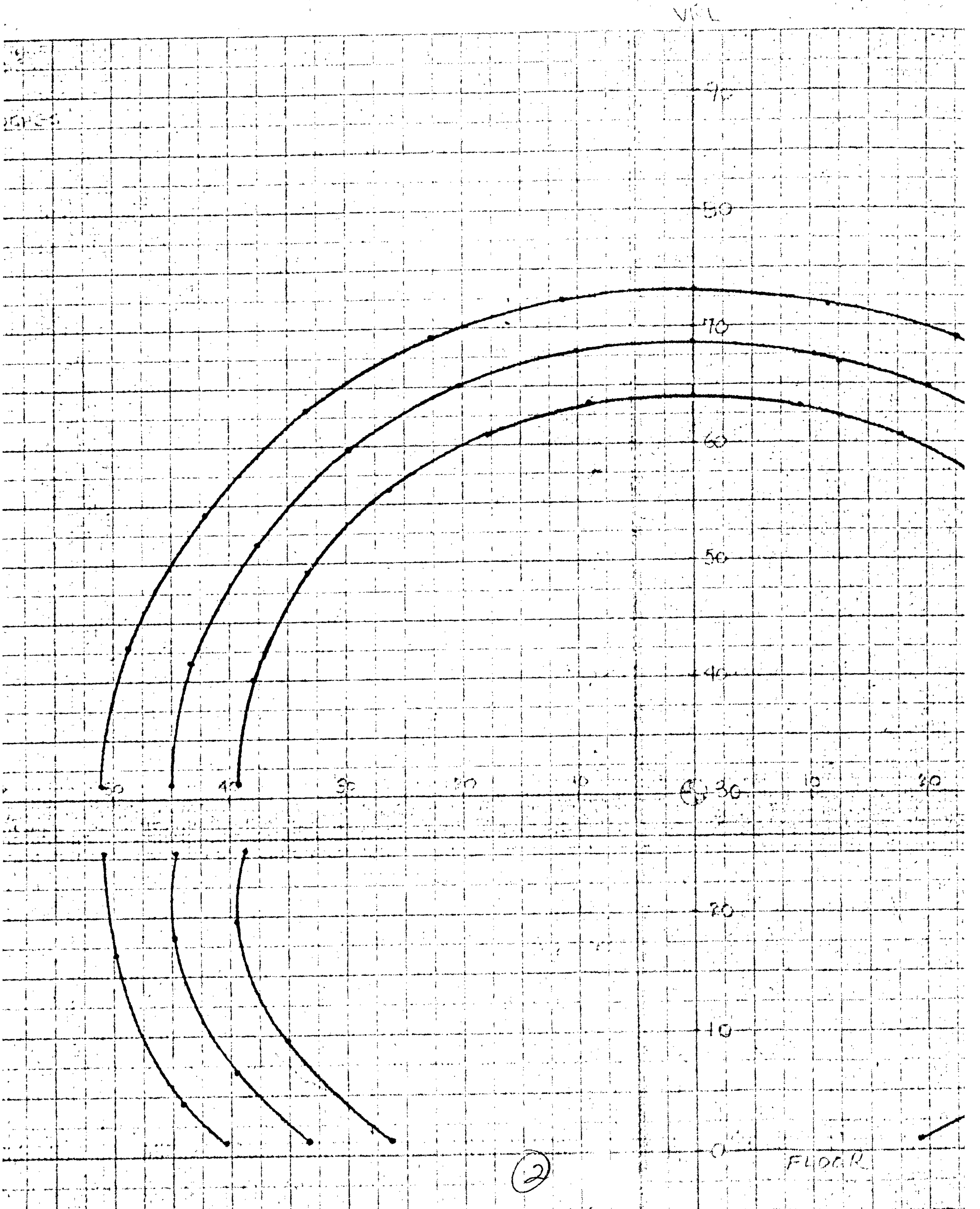

ARM REACH - RIGHT HAND
SHELF POSITION:
50TH
95TH
5TH
10
20
30
40
50
60
70
SHEET 2A

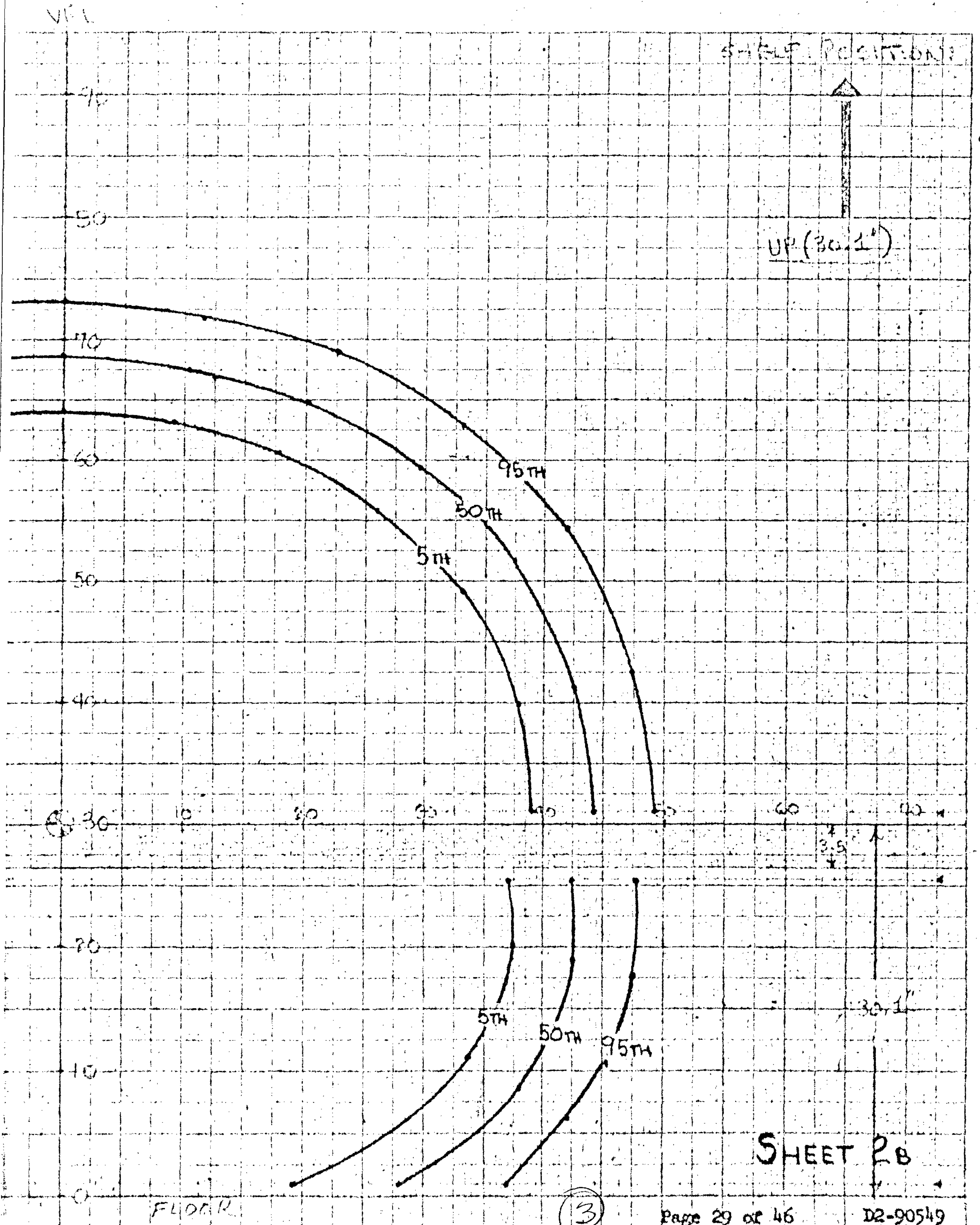
INSTRUMENT F

SHEET 2B



INSTRUME T RACK AF [illegible] CH - RIGHT



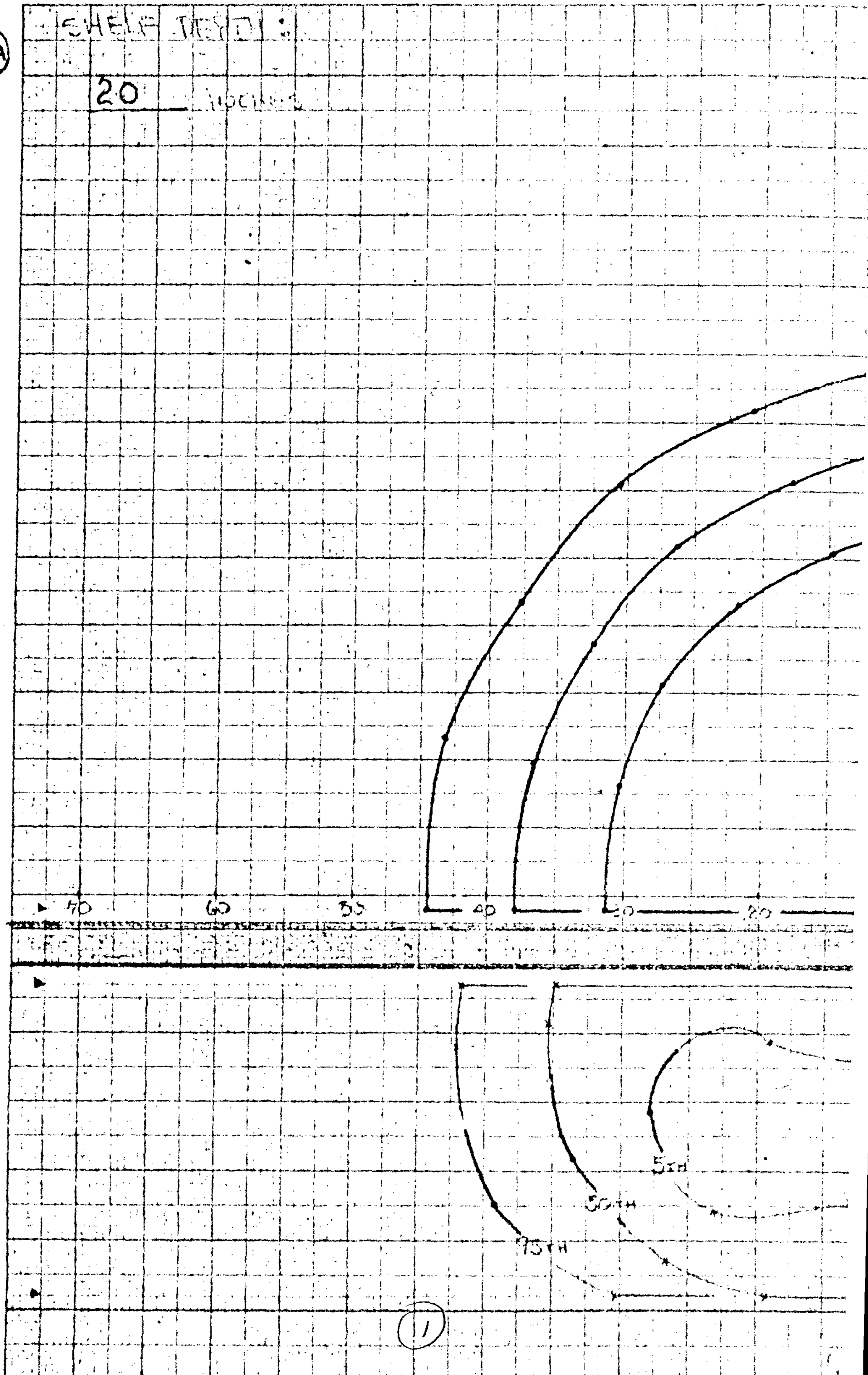


SHEET 2B

(13)

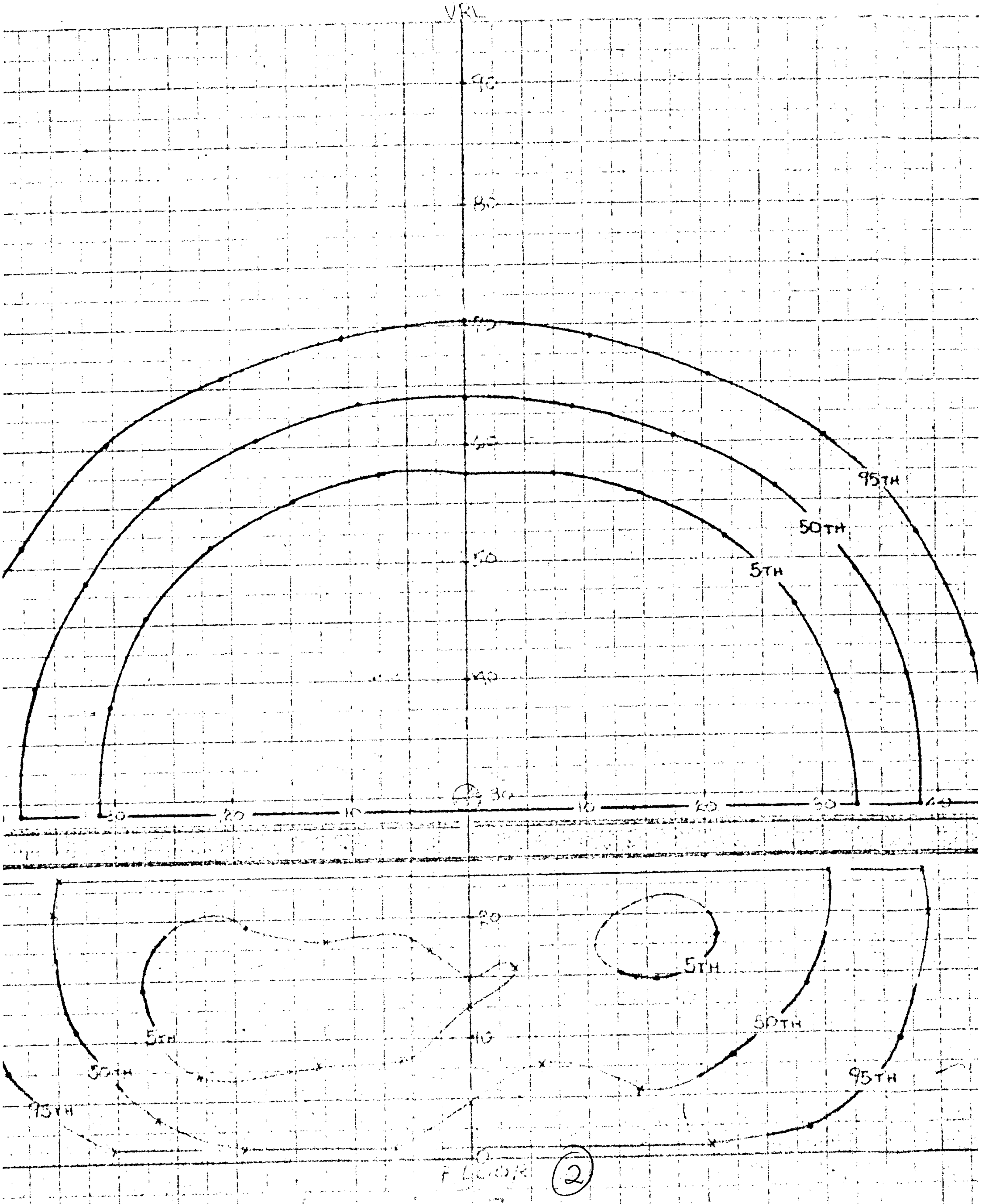
INSTRUMENT

SHEET 3A

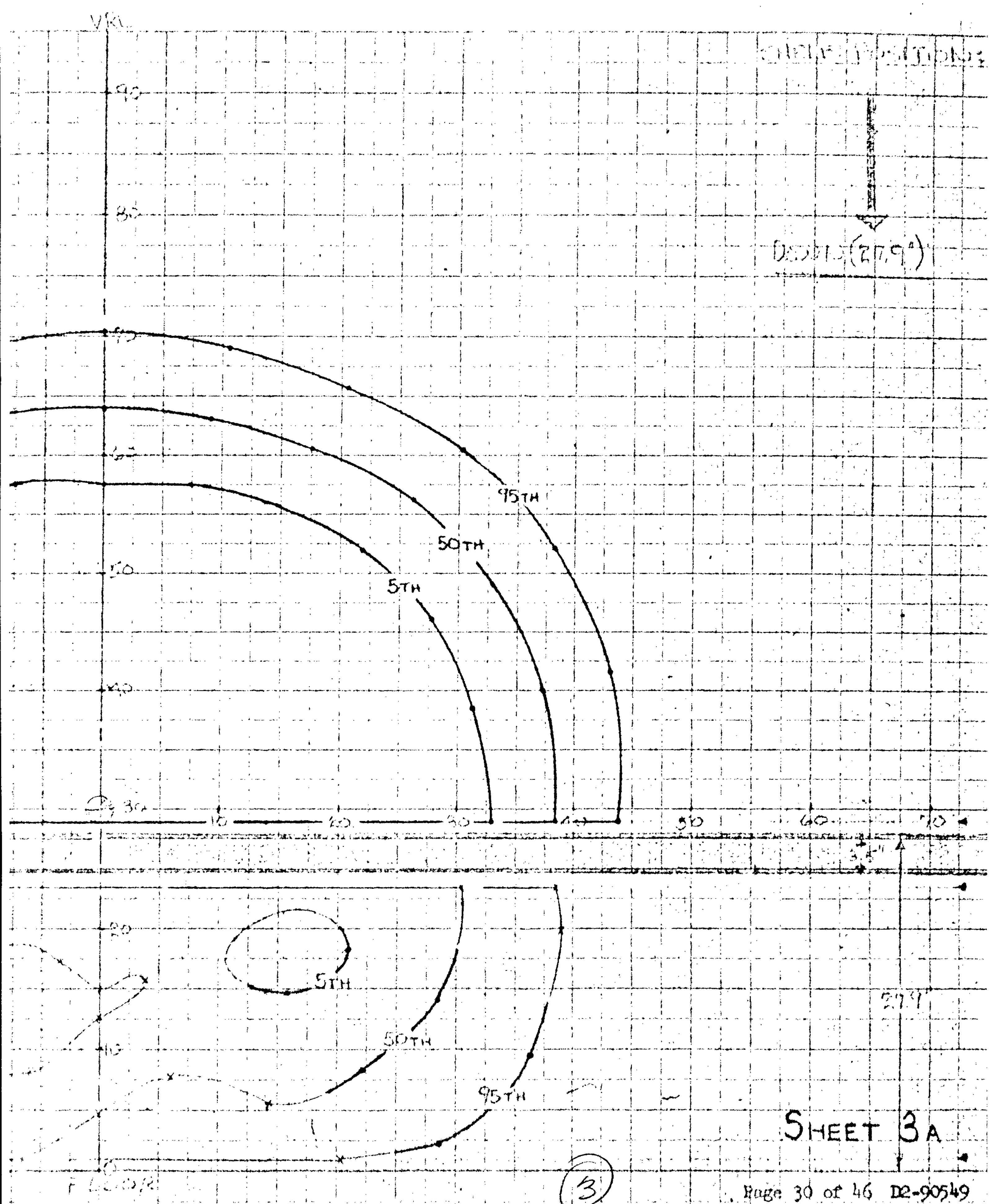


1

INSTRUMENT RACK ARM REACH - RIGHT HAND



(2)



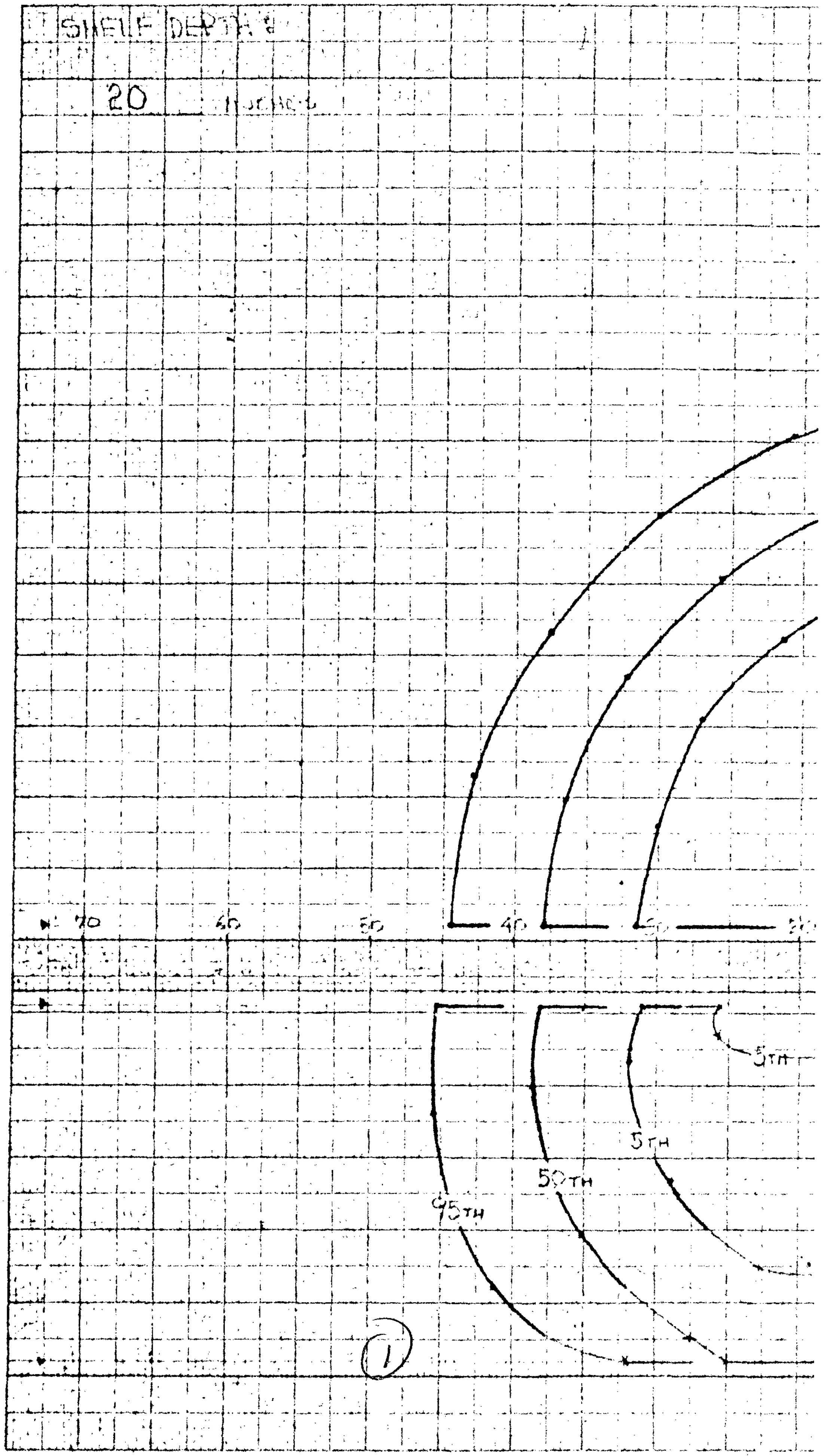
VRL
90
80
60
50
40
30
10
20
30
40
50
60
70
95TH
50TH
5TH
20
10
0
FLOOR
5TH
50TH
95TH
27.9"

SHEET 3A

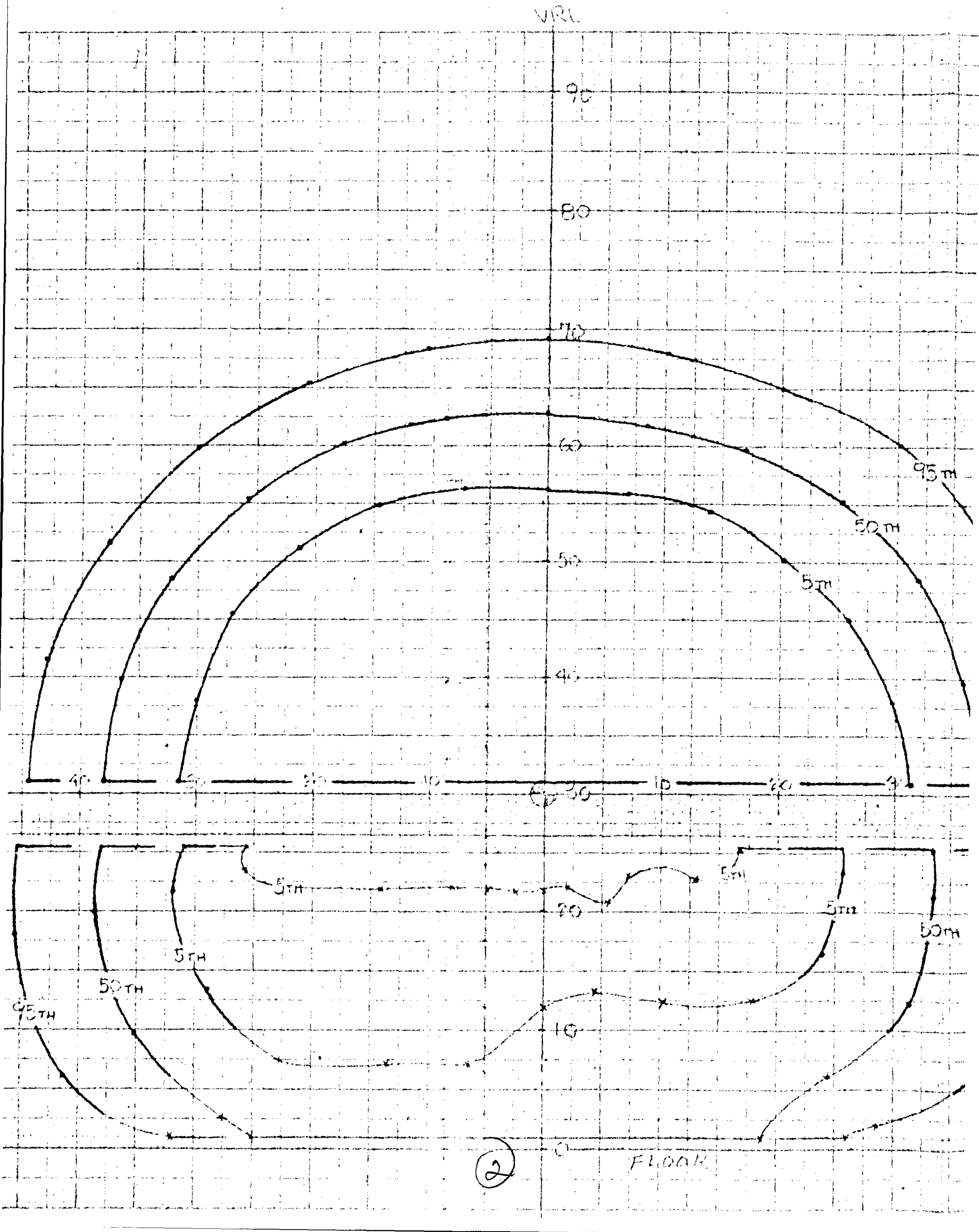
(3)

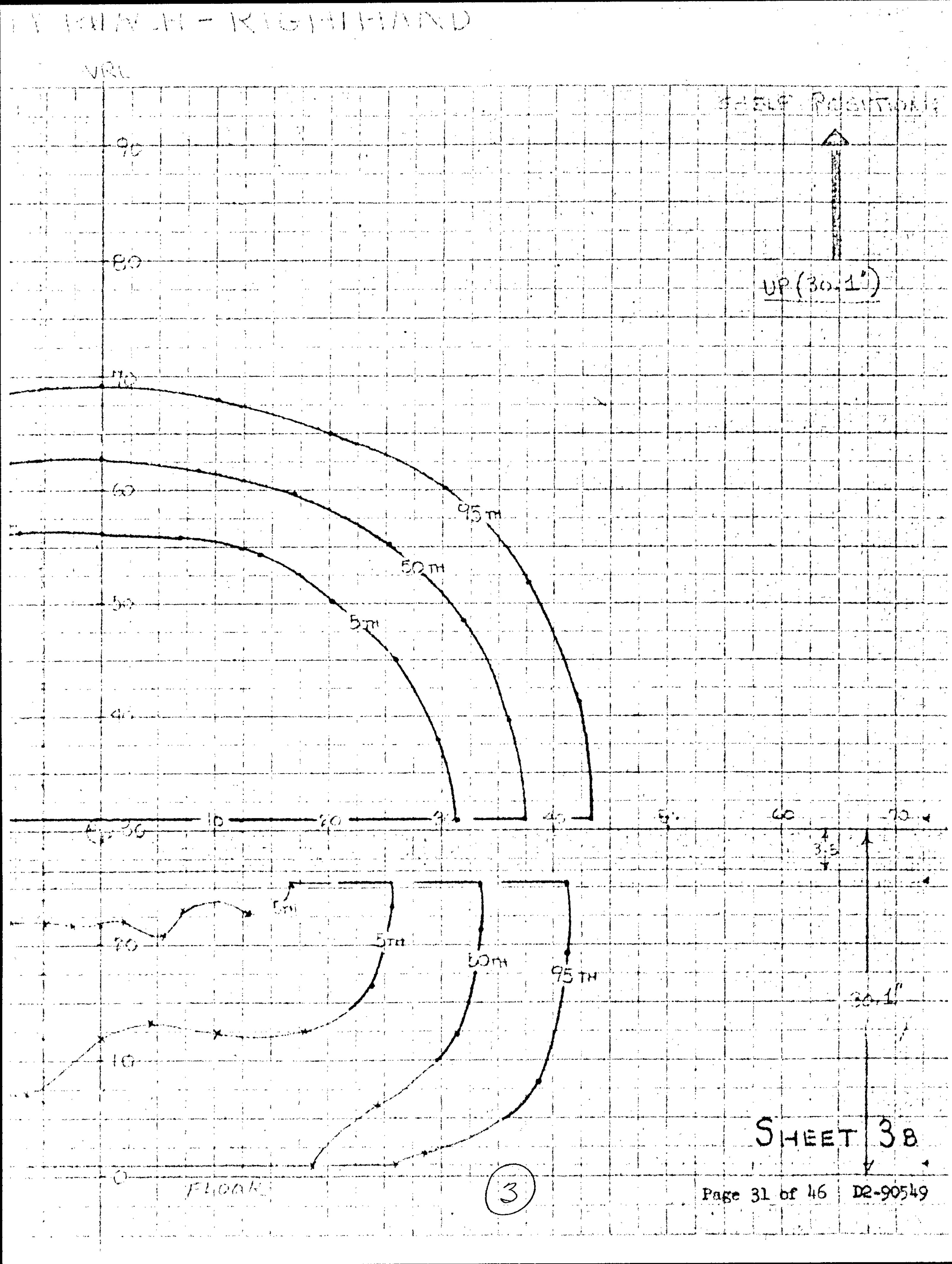
INSTRUMENT RA

SHEET 3B



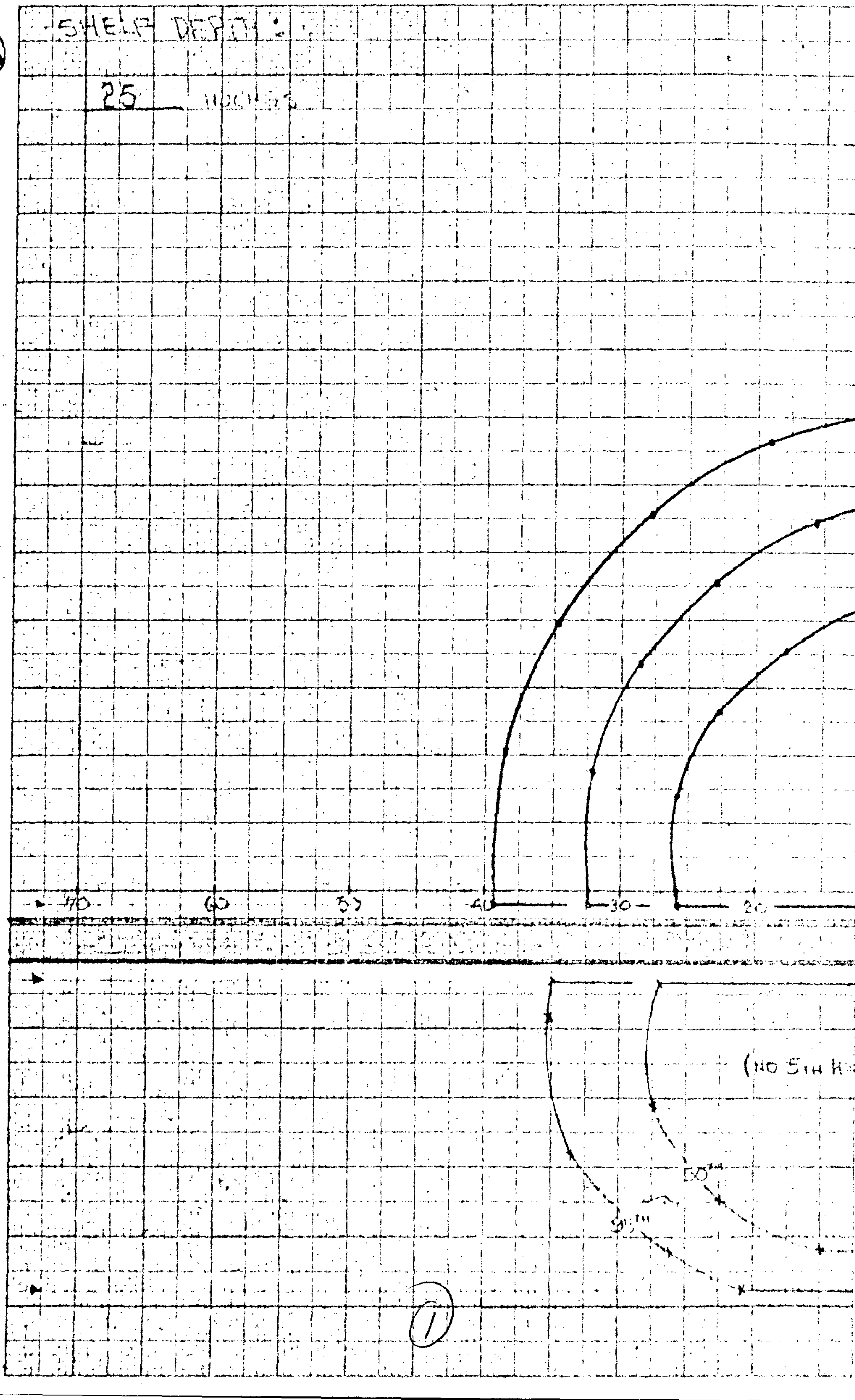
45° FUNCT'L REACH ARCH BENCH – RIGHTHAND



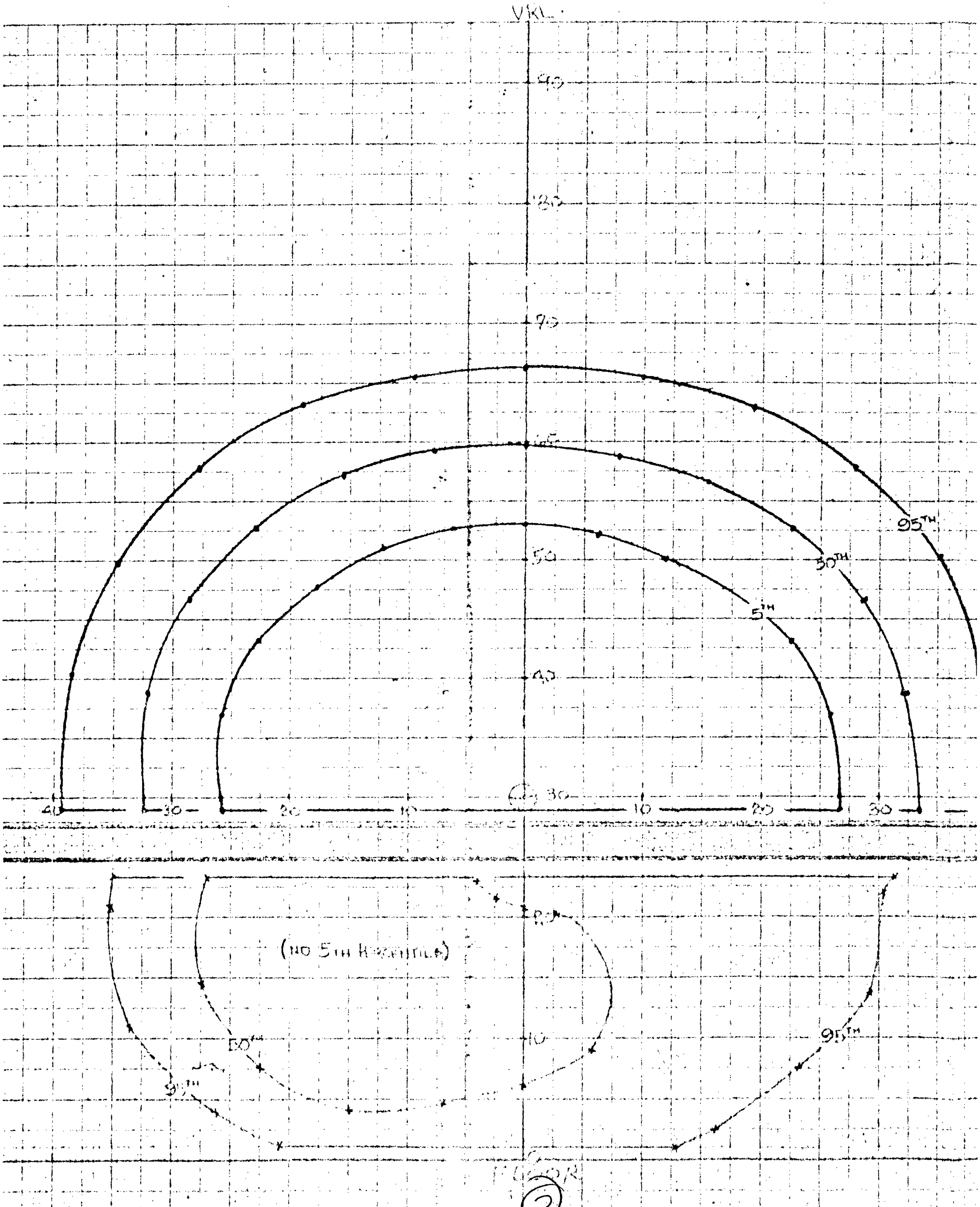

SHELF POSITION
UP (30.1")
VRL
90
80
70
60
50
40
10
20
30
40
50
60
70
3.5
95TH
50TH
5TH
30.1"
10
0
FLOOR
SHEET 3B

INSTRUMENT

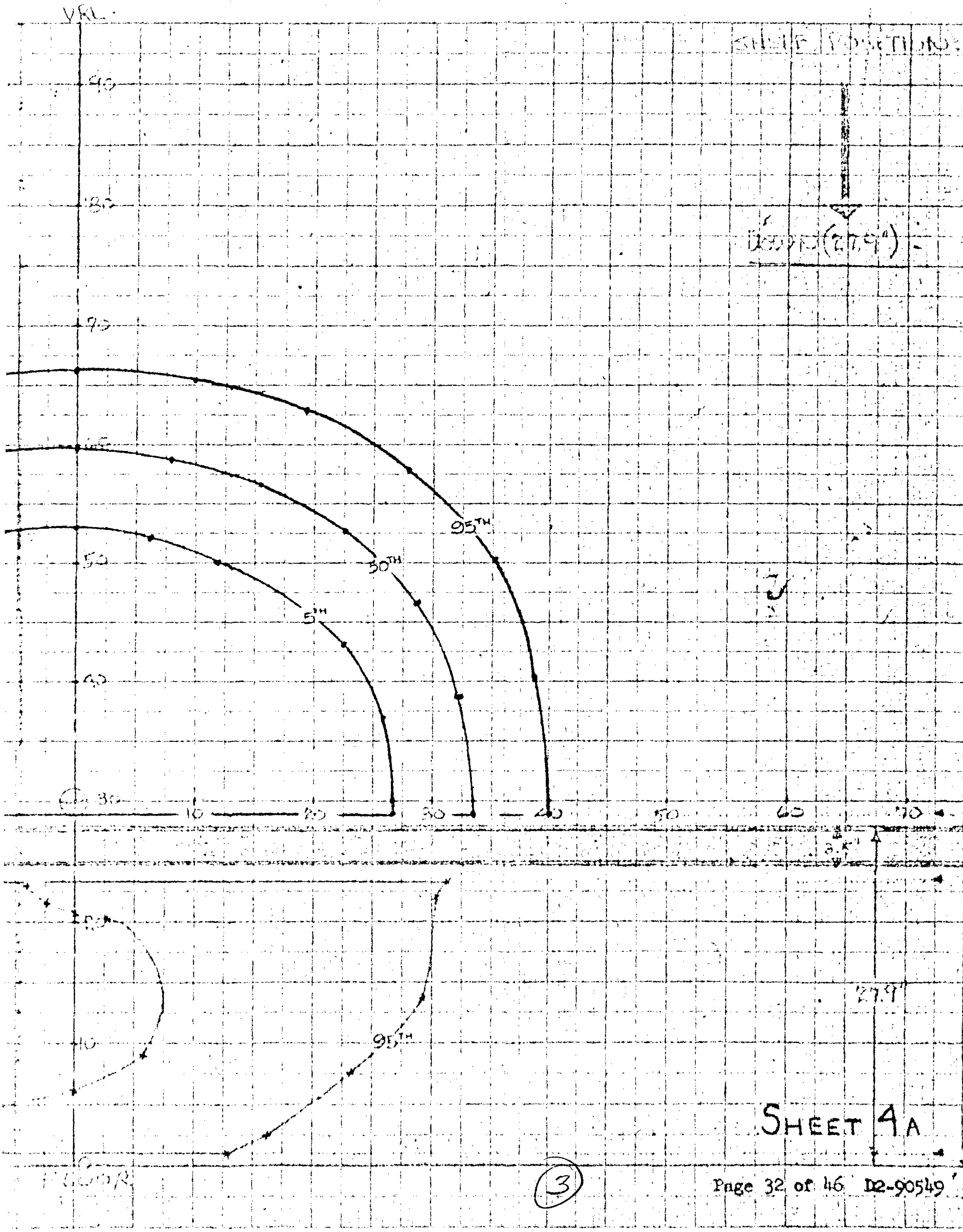
SHEET 4A



INSTRUMENT RACK/ARM REACH - RIGHT



R/ARM REACH - RIGHT HAND

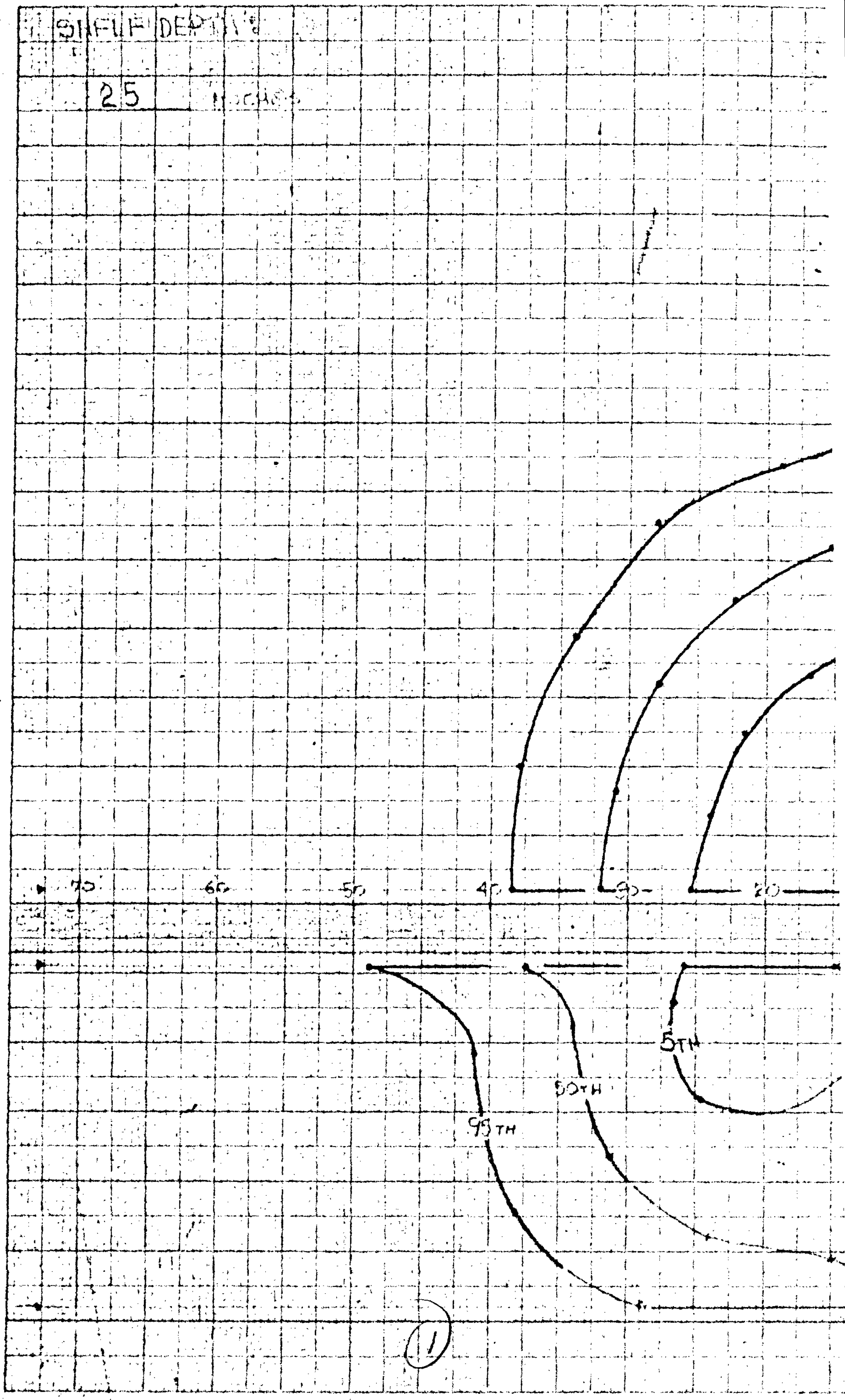


SHEET 4A

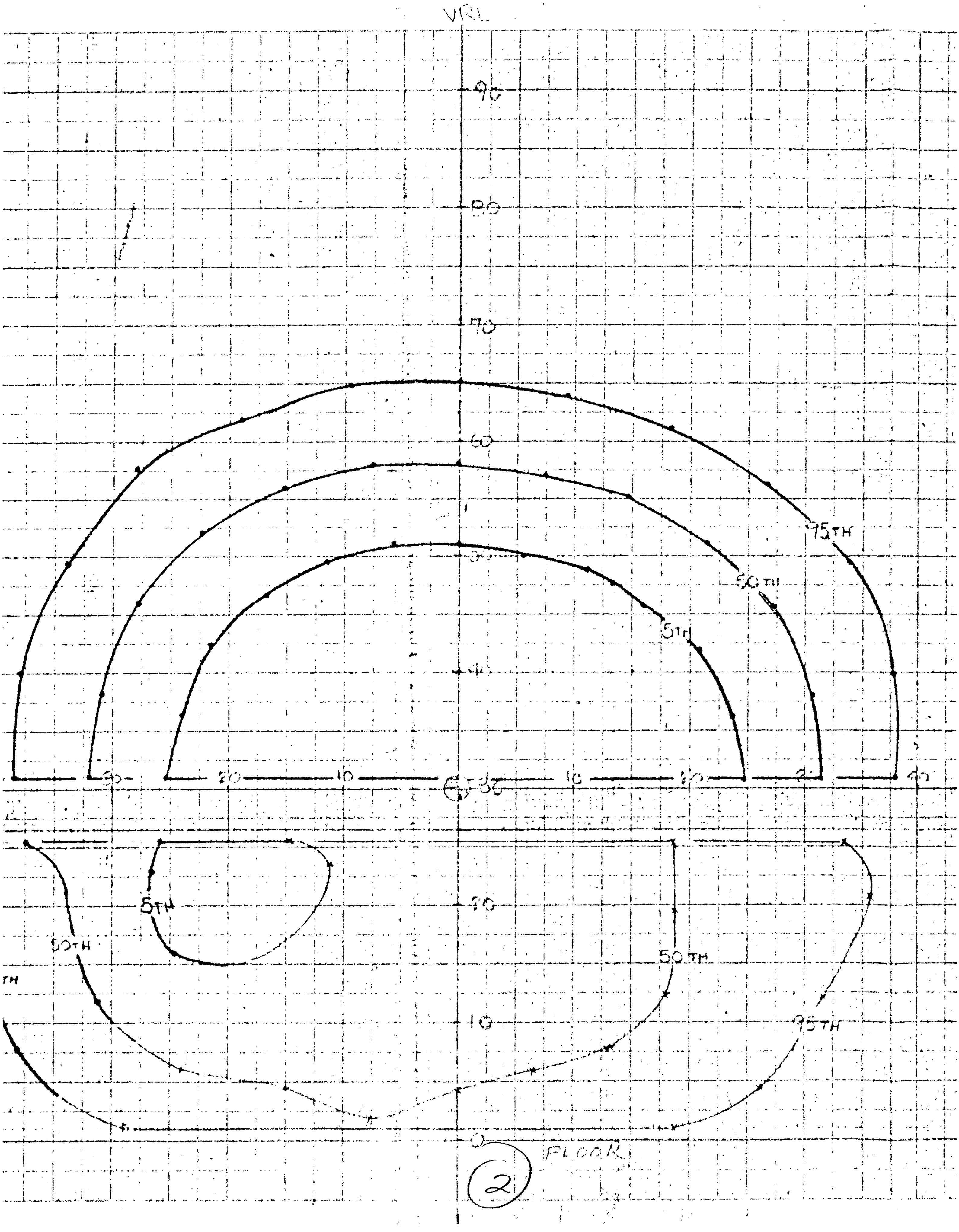
(3)

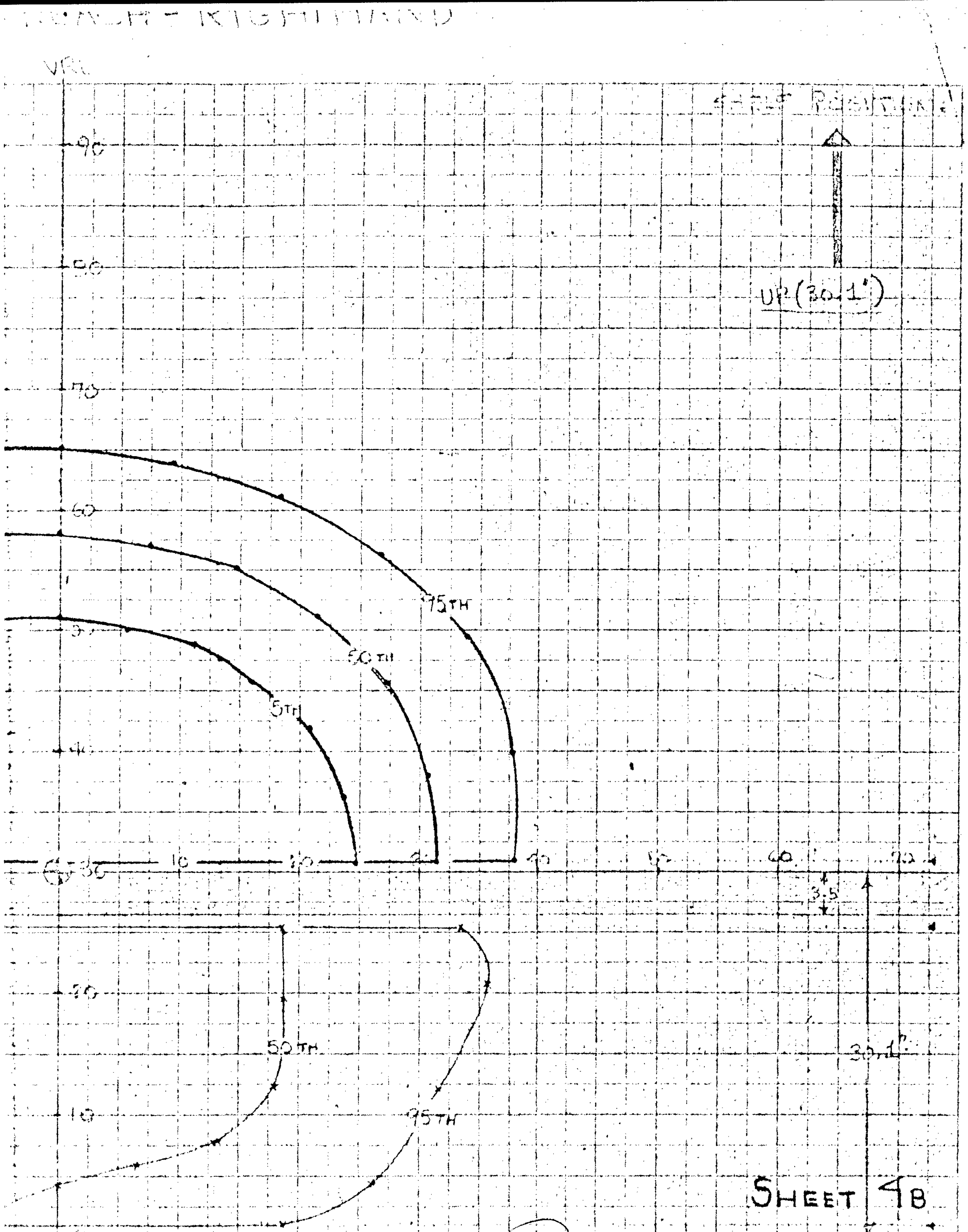
INSTRUMENT RACK

SHEET 4B



WOMEN BACK ARM REACH - RIGHT HAND




UP (30.1")
95TH
50TH
5TH
3.5
30.1"
50TH
95TH
SHEET 4B
FLOOR
3

Above the shelves in Sheets 3a through 4b the average as well as 5th and 95th-percentile contours were computed as a function of the mean and standard deviation after investigation showed that the data allowed normal (Gaussian) parametric statistical treatment. A heavy line is used to show this.

There are areas beneath the table, however, where the data are a mixture of numerical and go, no-go measurements. Here, the mean and the percentiles were determined directly by rank order. A lighter line is used to show this. Design decision based upon the areas enclosed by these light-lined boundaries should be conservative to allow for the more uncertain nature of such non-parametric (no mean or standard deviation) estimates.

In general, changing shelf depths and heights produced consistent as well as characteristic qualitative changes in arm reach. In the absence of a shelf (Sheet 1), and in the presence of a 10-inch shelf (Sheets 2a and 2b), the reach boundaries are generally smooth and elliptical in shape. With shelf depths greater than 10 inches this regularity of contour is seen only above the shelf.

Below it the boundaries become quite irregular. In fact, the 5th-percentile boundary disappears altogether in the presence of a 25-inch shelf placed in the low position (Sheet 4a: 27.9 inches above floor).

This irregularity is only partly caused by the uncertainties associated with direct estimate of percentiles. Arm reach beneath the table in the presence of the deeper shelves really is irregular because it is quite difficult to reach under the deeper shelves to both see and manipulate a control knob. This is particularly so with the deeper shelves in the lower (27.9 inches) position (Sheets 3a and 4a).

Arm reach with the right hand is slightly greater to the left of the origin than to the right. The amount -- about 1/2 to 3/4 inch -- although consistently observed, is not significant.

The more specific effects of varying shelf depth and height are best illustrated by comparing the mean (50th) boundaries of the seven test conditions. This is done graphically on Sheet 5 and reveals that:

1. Increasing shelf depth from 0 to 25 inches causes greater change in arm reach than does varying shelf height between 27.9 and 30.1 inches.

2. Shelf Depth

   a. Boundaries of mean (50th) arm reach decrease both above and below the shelf as shelf depth increases. In terms of radial distance from origin, the decrease is from 10 to 16 inches above the shelf but from 18 to 50 inches below the shelf.

   b. The change from no shelf to a 10-inch shelf reduces arm reach radially from 1 to 4 inches. This is negligible when compared with the decrease of 5 to 11 inches which results from changing from a 10-inch shelf to a 20-inch shelf, or the decrease of 4 to 24 inches caused by changing from a 20-inch to a 25-inch shelf.

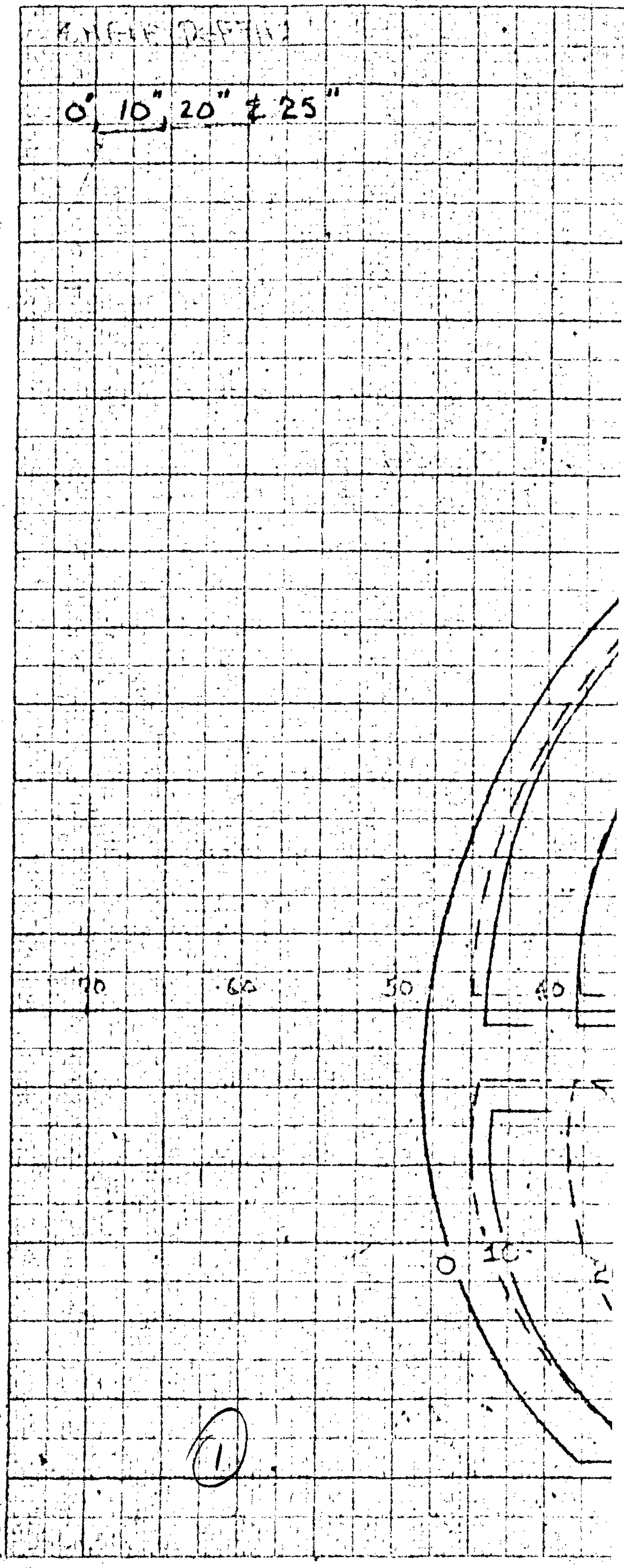
   c. Increasing shelf depth takes its greatest toll of arm reach beneath the shelf. This is particularly spectacular in the area to the right of the origin, where the decrease in arm reach can be as much as 50 inches.

3. Shelf Height

   a. The effect of variation in shelf height upon arm-reach boundaries above the shelf is just the opposite of the effect below the shelf. That is, boundaries of arm reach decrease slightly (0 to 2 inches) above the shelf when it is raised to 30.1 inches from 27.9 inches, but increase (0 to 23 inches) below the shelf.

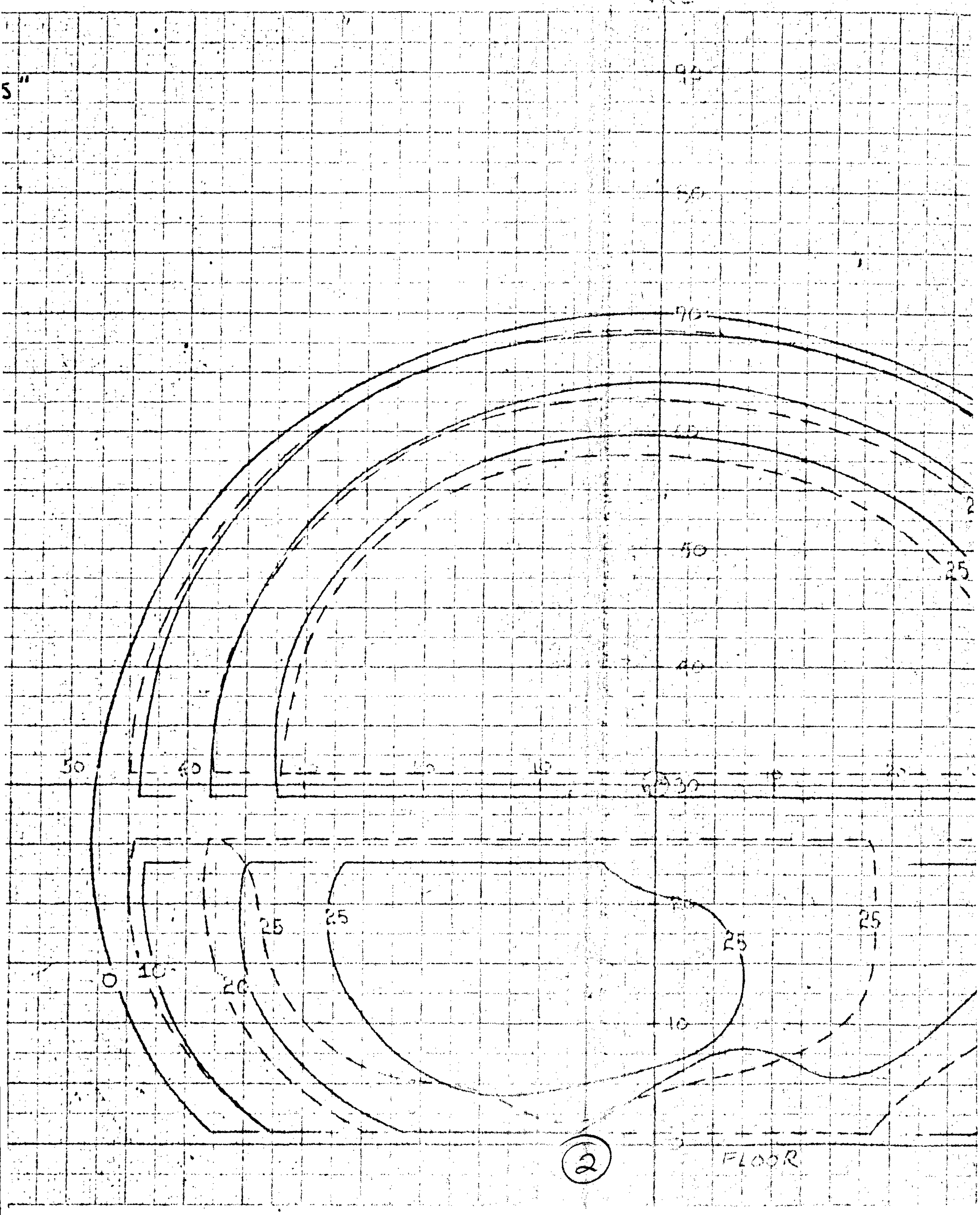
INSTR

SHEET 5



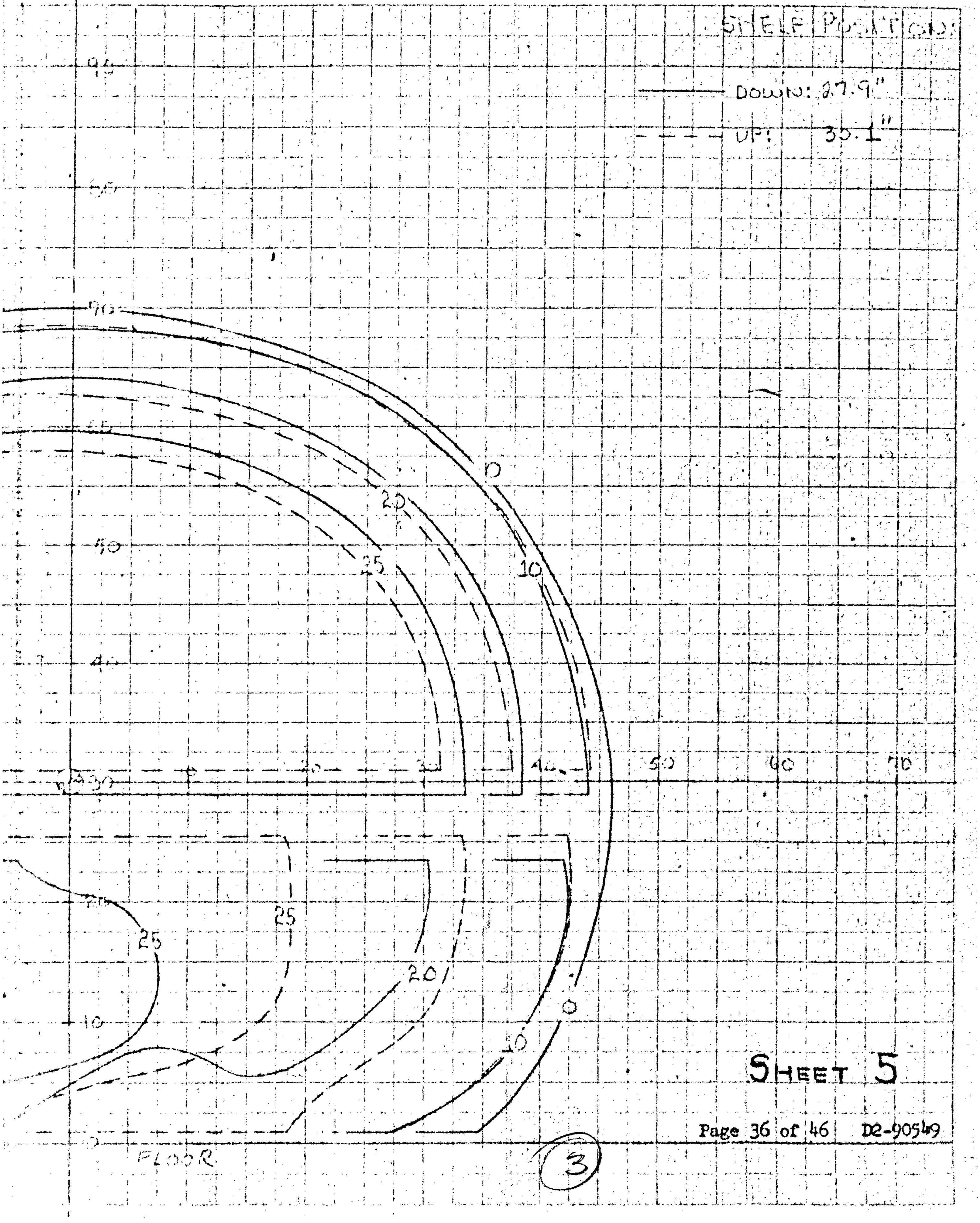
INSTRUMENT RACK ARM REACH—R

MEAN CONTOURS



2

ARM REACH - RIGHT HAND
CONTOURS
VRL



b. The effects upon arm-reach boundaries caused by variation in shelf height are quantitatively different for different shelf depths. For instance, there is no difference in arm reach between the 27.9-inch and 30.1-inch shelf heights in the case of the 10-inch shelf. With the 20-inch shelf, however, lowering it to 27.9 inches causes a 0 to 1-inch increase above the shelf, but a 2-1/2 to 4-inch decrease below it. Lowering the 25-inch shelf causes an even greater change: a small increase of 1 to 2 inches above the shelf but a 0 to 23-inch decrease below it.

c. It is of interest to note that for a given shelf depth the effects upon arm-reach boundaries are greater beneath the shelf than above it. This is most pronounced in the lower right-hand quadrant.

While it is best to comprehend these effects in terms of such a highly stable estimator of central tendency as the mean, design for reliability must also be based upon the variability of individuals about the mean. This variability is, like the mean itself, also affected by changes in shelf depth and shelf height. The usual measure of variability is the standard deviation, from which is derived an estimate of variability which is more useful in design. This is the spread or band width between 5th and 95th-percentile contours shown on Sheets 1a through 4b. Inspection of these band widths shows that with regard to the effects of shelf depth:

- The bandwidths above the shelf increase slightly but not significantly with increasing shelf depth.
- The bandwidths below the shelf increase markedly with increase in shelf depth.

With regard to the effects of shelf height:

- For a given shelf depth, the bandwidth above the shelf is not affected by changes in height.
- For the 20 and 25-inch shelf depths (Sheets 3a through 4b), the bandwidths below the shelves are markedly greater at the 27.9-inch height than at the 30.1-inch height. In contrast, the bandwidth is unaffected by changes in 10-inch shelf height.

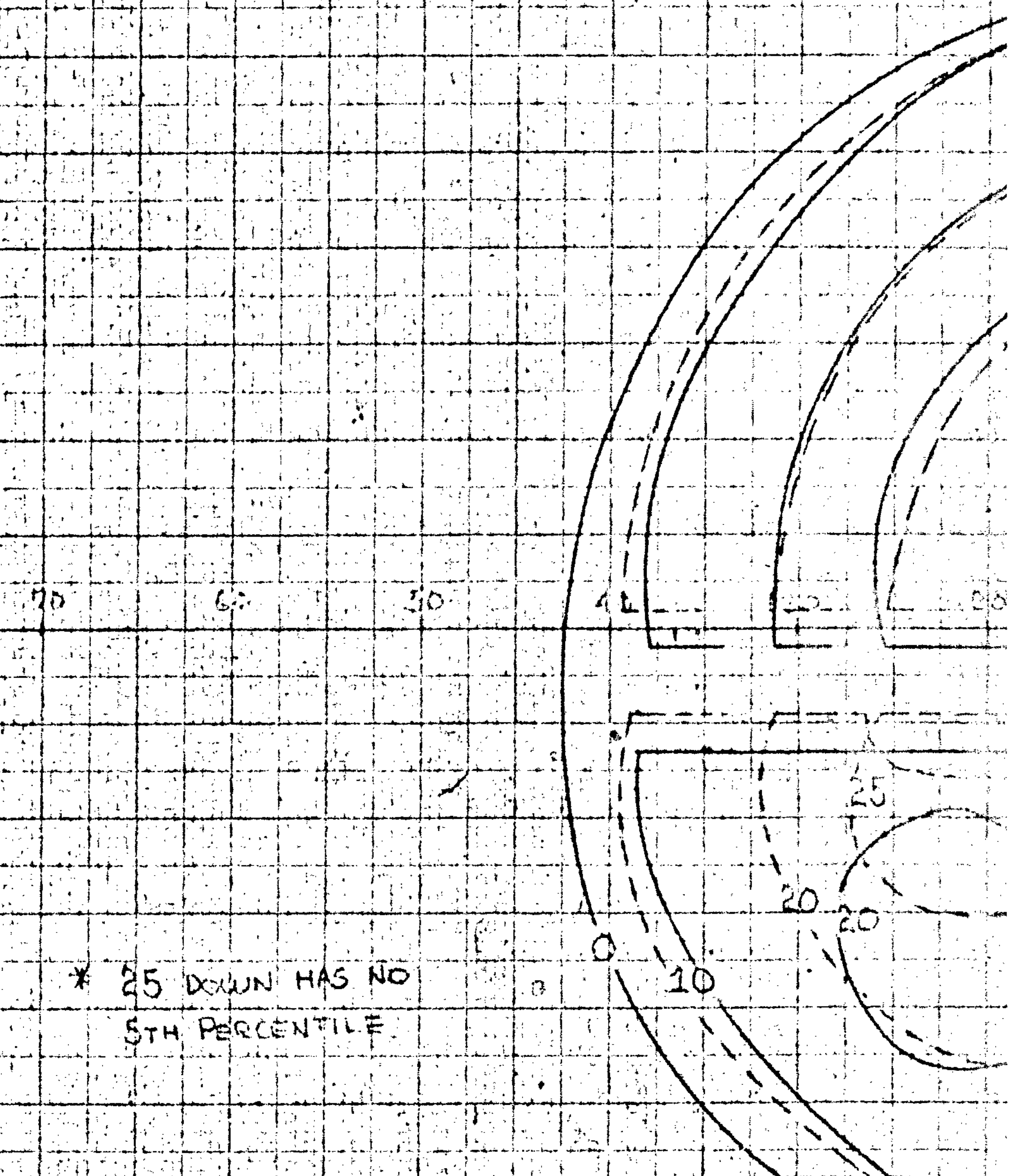
The 5th-percentile arm-reach contours have special significance in applying the results of this study to systems design. Military design and procurement specifications [1, 6] emphasize that equipment shall be designed to allow at least 90- and preferably 95 percent of the prospective operators to perform adequately. Put into a reliability framework, the design should be such that it is 95 percent certain that the population of potential operators will be able to perform tasks adequately.

Design of instrument-rack tasks similar to that studied and which require "maximum" reach capability will be based, therefore, on those reach contours which define the area within which 95 percent of the operators can reach. These are the areas enclosed by the 5th-percentile contours which are compared on Sheet 6. These contours are called 5th-percentile because only 5 percent of the expected population have shorter reaches than this. They can equally well be called 95 percent <u>reliability</u> contours because 95 percent of the expected population can reach at least to these boundaries.

Since the 5th percentile is computed from the mean and standard deviation (except where noted by a thinner line on Sheets 3a through 4b), it is not surprising that essentially the same effects of shelf depth and height are noted on 5th-percentile reach contours as are seen on the mean contours, i.e. decrease in reach with increase in shelf depth, decrease in reach above shelf with increase in shelf

SHEET 6

0" 10" 20" & 25"



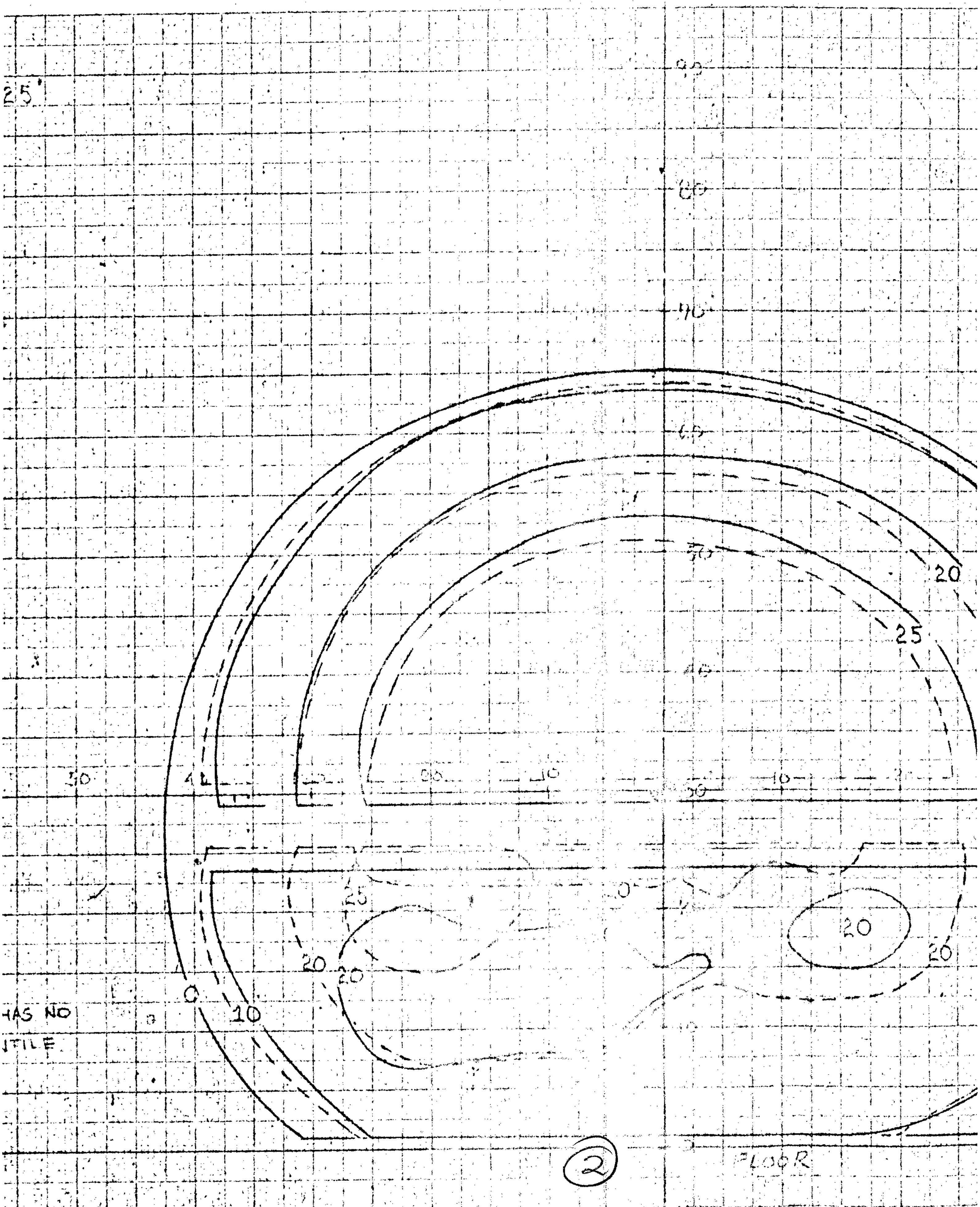
* 25 DOWN HAS NO
5TH PERCENTILE

(1)

INSTRUMENT RACK ARM REACH-R

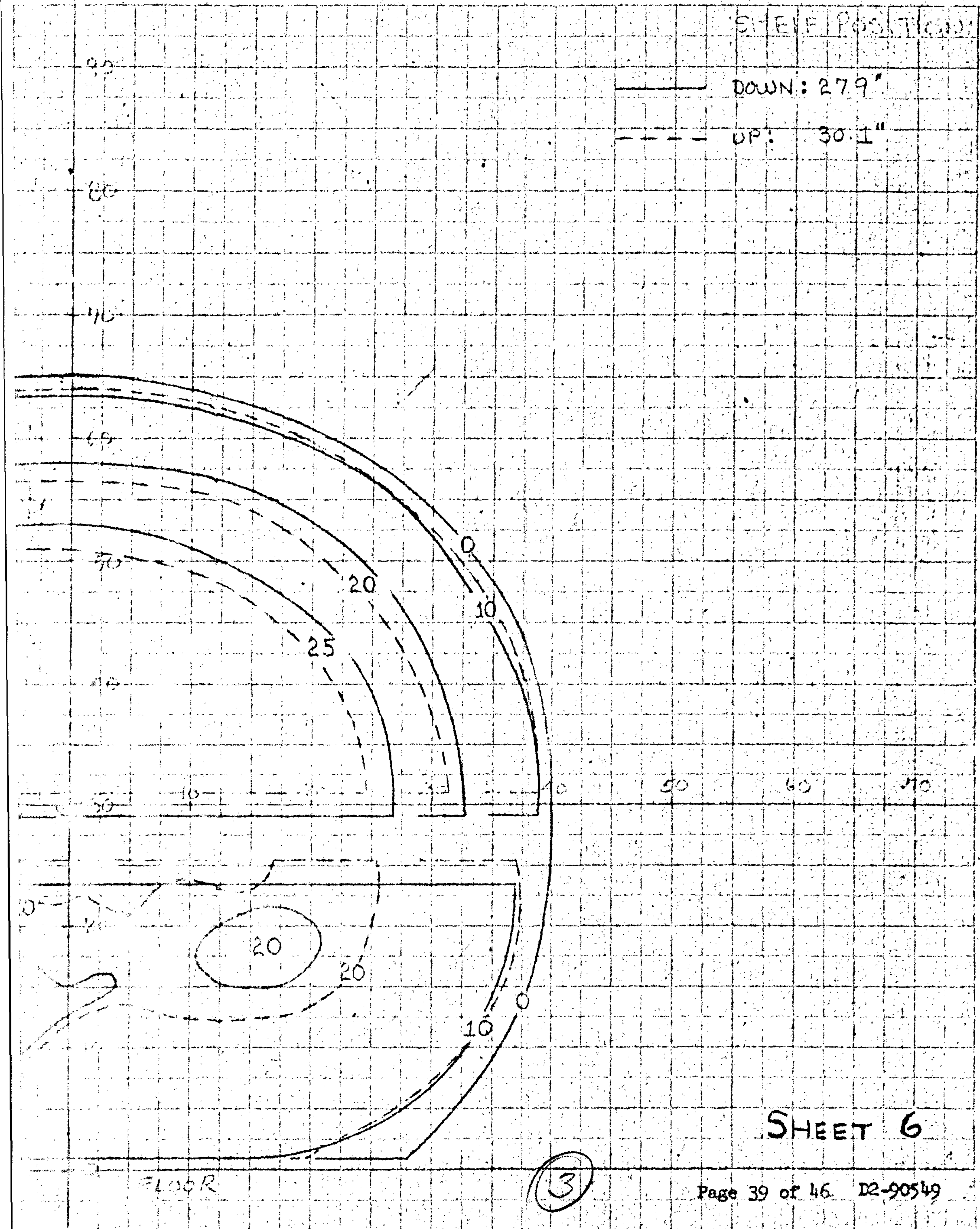
5TH PERCENTILE CONTOURS

VRL



ARM REACH - RIGHT HAND

TILE CONTOURS



height but increase below shelf, effects much greater below shelf, arm reach slightly greater to the left than to the right, etc.

It should be noted that there is no 5th-percentile contour when the 25-inch shelf is positioned 27.9 inches above the floor. This means that there is no place on a rack beneath such a shelf where a control can be located and still have a 95-percent chance of being seen and actuated.

B. Body Size, Preferred Seat Height and "Functional Clearance"

Insofar as height and weight indicate overall body size, our test sample satisfactorily represents the expected or "model" population of users. Using the mean (average) as an index of central tendency and the standard deviation as an index of variability about the central tendency, Table I shows a favorable comparison with the model of the using population. Fifth and 95th percentiles are also given. The mean heights differ by only 0.05 inch and the corresponding standard deviations, by only 0.12 inch. Because subjects were selected on the basis of height, this is not surprising -- it merely shows that the selection procedure was successful.

Weights, although not controlled in the selection, also correspond rather well, the test sample subjects being on the average about 5.1 lbs. heavier than members of the model population. Individual variability is somewhat less in the test sample than that expected in the model population, the standard deviation of the test group being 4.13 pounds less. These slight differences in height and weight parameters between the test sample and the model population are not statistically significant. Therefore, the arm-reach data should, insofar as body size affects them, be adequately representative of the arm reach of the model population.

TABLE I

COMPARISON OF TEST SAMPLE AND USING POPULATION
BODY SIZE AND SUMMARY OF SEAT-HEIGHT AND CLEARANCE RESULTS

	Stature*		Weight*		Preferred Seat Height	Functional Table Clearance
	Test Sample	Model+	Test Sample	Model+		
Mean	69.16	69.11	168.8	163.7	13.34	23.70
Standard Deviation	2.56	2.44	16.73	20.86	0.68	0.76
5th Percentile	64.95	65.2	141.28	132.5	12.22#	22.45
95th Percentile	73.37	73.1	196.32	200.8	14.46#	24.94

* No significant difference between study subject group and model population either in means or standard deviations.

\+ Reference (3).

\# Adjustment range of a standard office chair such as Steelcase is: 11.2 to 15.4.

There are no data on preferred seat-height adjustment, when seated in an office chair, for the model population. Therefore, it must be assumed that insofar as seat adjustment affects arm reach the arm-reach data of this study reflect the effects of seat-height adjustment in the using population. Mean and standard deviations together with 5th and 95th percentiles of seat-height adjustment and associated "functional clearance" are given in Table I.

It is interesting to note that a Steelcase office chair has a height-adjustment capability of 3.2 inches, that is from 11.2 to 15.4 inches above the floor in terms of the chair reference point. Table I shows, however, that 90 percent of the expected users in the model population would be adequately accommodated by an adjustment range of no more than 2-1/4 inches, that is from 12.22 (5th percentile) to 14.46 (95th percentile) inches. In fact, an adjustment range of no more than 2.7 inches is required to comfortably accommodate over 95 percent of the expected users in the model population.

It is also of interest to note how well initial predictions for minimum shelf-height clearance were validated by the results of "functional clearance" measurements. These show that the bottom of a shelf can be no lower than 24.94 inches above the floor if 95 percent of the expected users are to have adequate "functional clearance" beneath it. This tends to validate the selection of 27.9 inches as the minimum height for the top of a 3-1/2-inch thick shelf. Such a shelf would thus provide 27.9 inches - 3.5 inches, or 24.4 inches of clearance.

This is one-half inch less than seems desirable for "functional clearance" as defined but would yet allow the lower extremity to fit under it. Raising such a 3-1/2-inch thick shelf the indicated 1/2 inch would provide adequate "functional clearance" for 95 percent of the users and would place the top surface of the shelf only 0.4-inch higher than 28 inches, the most desirable shelf-surface height (7, 8).

CONCLUSIONS

The boundaries of maximum arm reach for knob turning with the right hand, on a vertical instrument rack, are shaped somewhat like flat ellipses turned on their sides.

Arm reach to the left is slightly greater than to the right.

The presence of a shelf on the rack face decreases reach. If maximum arm reach is a critical factor and yet a shelf is necessary, there will be little reduction in arm reach if shelf depth is limited to 10 inches.

In terms of maximum arm reach, it makes little difference whether such a shallow shelf is located 27.9 inches or 30.1 inches above the floor. In terms of the suitability of the shelf per se, past research shows the lower height to be more satisfactory of the two tested.

The underneath surface of a shelf should be no closer to the floor than 25 inches, regardless of its depth, if 95 percent of the using population is to be afforded minimum functional clearance beneath it.

If the top of a 3-1/2-inch thick shelf is positioned at about 27.9 inches above the floor, the depth of this shelf may be more than 20 inches but must be less than 25 inches if 95 percent of the operators are expected to see and twist a knob located beneath it.

RECOMMENDATIONS

It is recommended that the 5th-percentile contours of instrument-rack arm reach shown on Sheet 6 be taken as the absolute maximum capability (at the 95-percent reliability level) for a seated position such as studied. Where a standard office chair is to be used which is free to move laterally, this would be a band of infinite limits to the right and left across the rack and whose height above and below the origin would correspond to the maximum vertical (up and/or down) limits shown for the appropriate shelf depth and height on Sheet 6.

It is strongly recommended that routine rack tasks which are repetitive or critical be located well inside these limits to avoid poor performance or excessive fatigue in the operator. The limits shown are the result of maximum effort. They are not optimum!

It is recommended that discretion be used in the application of these data. The results of this study are most accurately descriptive of performance in situations closely resembling those simulated in the study, i.e. office chair, 3-1/2-inch thick horizontal shelves, simple vertical display surface. Arm-reach data are strongly dependent upon the task to be performed, body support used and obstructions encountered. Uncritical application of these data to complex consoles, for example, those which have variously oriented display surfaces and a tilted "shelf," together with stringent read-out requirements, would be a great mistake if one wished a realistic estimate of operational adequacy.

In such instances, it would be far more reliable to get "quick-and-nasty" estimates from say, two subjects (one at the 5th percentile in stature and one at the 95th) using a cardboard mock-up of the proposed design. Also, it should be cautioned that these data may not be valid where actuating forces are different from those tested (0 ounces for torque, 28 ounces for contact force). In line with this warning as to the limitations of the data, three areas are recommended for further study:

1. Arm reach on complex console-type display surfaces.
2. Arm reach for actuation tasks involving the current and/or suggested range of forces encountered on knobs, switches, buttons and selectors.
3. Development of a statistical model for analyzing the significance of those rack and console-design parameters which seem to affect arm reach.

It is further recommended that seated work surfaces be no higher than 28 inches above the floor and be as thin as structurally possible, to provide adequate leg clearance.

REFERENCES

1. Department of the Air Force, Human Engineering Design Criteria for Aerospace System Ground Equipment, MIL STD-803A (USAF), 1 February 1963, p. 9-4.

2. Akerblom, Bengt, "Chairs and Sitting," in: Human Factors in Equipment Design, W. F. Floyd and A. T. Welford, Eds., Vol. II, Proceedings of the Ergonomics Research Society, H. K. Lewes and Co., Ltd., London, 1954.

3. Hertzberg, H. T. E., G. S. Daniels and E. Churchill, Anthropometry of Flying Personnel - 1950, WADC TR-52-321, Wright Air Development Center, W-P AFB, Ohio, September 1954, p. 23.

4. Martin, W. Edgar, Children's Body Measurements for Planning and Equipping Schools, Special Publication No. 4, U.S. Department of Health, Education and Welfare, Office of Education, U.S. Govt. Printing Office, Washington, D.C., 1960, pp. 20 and 21.

5. Emanual, Irvin I., personal communication.

6. U.S. Air Force, Handbook of Instructions for Aircraft Designers, Vol. 1 - Piloted Aircraft, ARDCM-80-1, p. C.2.1, 1 April 1963.

7. British Standards Institution, Anthropometric Recommendations for Dimensions of Non-Adjustable Office Chairs, Desks and Tables, B.S. 3079: 1959, British Standards House, 2 Park St., London, w. 1, Audley, London, 1959, pp. 6 and 7.

8. British Standards Institution, Anatomical Physiological and Anthropometric Principles in the Design of Office Chairs and Tables, B.S. 3044: 1958, British Standards House, 2 Park St., London, W.1, Audley, London, 1958, p. 16.